May 1996

ECOSYSTEM DIAGNOSIS AND TREATMENT (EDT)

Applied Ecosystem Analysis - Background

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Applied Ecosystem Analysis - *Background*

Mobrand Biometrics Inc

Prepared for
US Department of Energy
Bonneville Power Administration
Environmental Fish and Wildlife
PO Box 3621
Portland, OR 97208-3621

Project Number 9404600
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Applied Ecosystem Analysis - *Background*

This volume consists of eight separate reports. We present them as background to the Ecosystem Diagnosis and Treatment (EDT) methodology. They are a selection from publications, white papers, and presentations prepared over the past two years. Some of the papers are previously published, others are currently being prepared for publication.

List of Reports Contained in this Volume.

Report #1	An Ecosystem Strategy
Report #2	An Approach to the Diagnosis and Treatment of Depleted Pacific Salmon Populations in Pacific Northwest Watersheds
Report #3	Analysis of Chinook Salmon in the Columbia River from an Ecosystem Perspective
Report #4	A History of Frameworks Used in the Management of Columbia River Chinook Salmon
Report #5	Chinook Salmon (Oncorhynchus tschawytscha) in the Columbia River: The Components of Decline
Report #6	An Approach to Describing Ecosystem Performance "Through the Eyes of Salmon"
Report #7	Examples of the Use of a Trivariate Performance Measure
Report #8	A Strategy for Implementing the Fish and Wildlife Program in an Ecosystem Context

In the early to mid 1980's the concern for failure of both natural and hatchery production of Columbia river salmon populations was widespread. The concept of supplementation was proposed as an alternative solution that would integrate artificial propagation with natural production.

In response to the growing expectations placed upon the supplementation tool, a project called Regional Assessment of Supplementation Project (RASP) was initiated in 1990. The charge of RASP was to define supplementation and to develop guidelines for when, where and how it would be the appropriate solution to salmon enhancement in the Columbia basin.

The RASP developed a definition of supplementation and a set of guidelines for planning salmon enhancement efforts which required consideration of all factors affecting salmon populations, including environmental, genetic, and ecological variables. The results of RASP led to a conclusion that salmon issues needed to be addressed in a manner that was consistent with an ecosystem approach. If the limitations and potentials of supplementation or any other management tool were to be fully understood it would have to be within the context of a broadly integrated approach - thus the Ecosystem Diagnosis and Treatment (EDT) method was born.

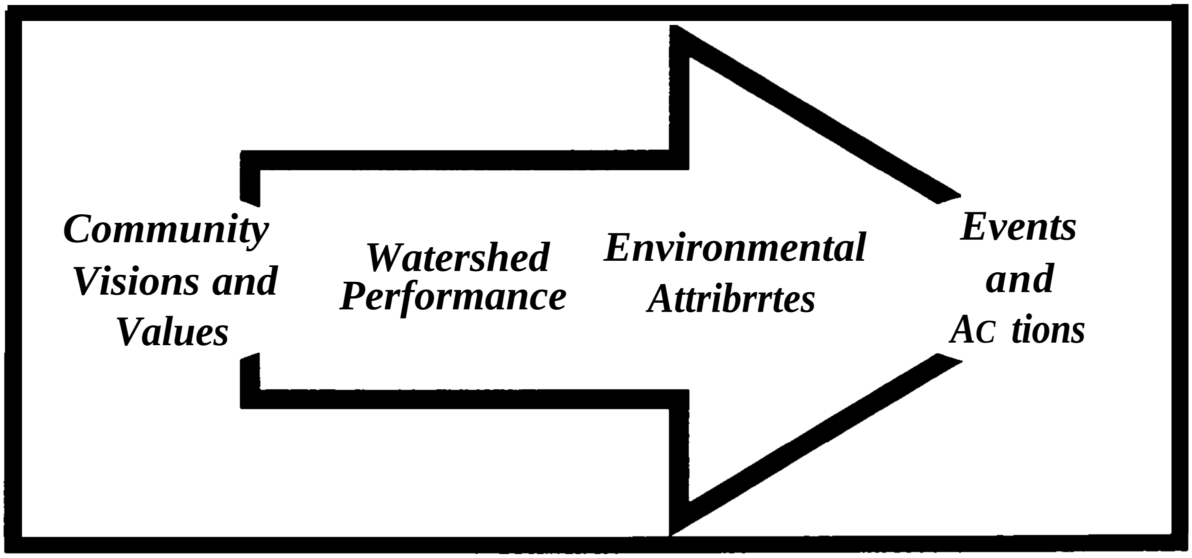
The reports contained in this volume address the need for an ecosystem consistent approach, examines some of the problems that the lack of an integrated approach has caused in the past, and describes some of the components of a solution to the problem. A companion volume is an EDT primer. It describes the procedures for applying the EDT in greater detail.

The first of the papers that follow presents an argument for adopting an Ecosystem Strategy. The second report introduces the EDT approach as a method of addressing salmon issues consistent with ecosystem concepts. It was published in the January, 1995 issue of Fisheries magazine.

The third report is an analysis of Columbia river chinook salmon from an ecosystem perspective. Reports four and five are historical reviews that chronicle how we got into the mess we're in, and why we need a new framework for management.

Reports six and seven define characteristics of an ecosystem that determine its performance. These characteristics are the fundamental elements of the EDT conceptual framework.

The final paper was prepared in the summer of 1995 in response to a request to give an example of how the EDT approach might be useful to the process of sequencing the implementation of the measures in the Fish and Wildlife Program.



An Ecosystem Strategy

The Case for Using an Ecosystem Strategy to Implement
the Northwest Power Planning Council's Fish and Wildlife Program
in the Columbia River - and Arguments in Support of the
Ecosystem Diagnosis and Treatment Method as Such a Strategy

A White Paper and Slide Presentation

May 1996

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WORKABLE POLICY SOLUTIONS FOR SALMON RECOVERY

"Status Quo, you know that is Latin for 'The Mess We 're In.'"

-President Ronald Reagan

This white paper will explore how an Ecosystem Strategy can help to provide the decision makers in the region with workable and effective solutions to the salmon crisis in the Columbia River Basin. Among the issues we will address are:

- **Why** adopting an Ecosystem Strategy is necessary;
- **What** specific solutions does it offer to decision makers and managers, in resolving the problems we face today;
- **How** we can put it into practice in the "Real World."

This examination of why an Ecosystem Strategy is necessary starts by taking a look at our status quo and the mess that we must confront.

The Failure of the Status Quo

The current restoration program traces its roots back to the 1940's. At that time, the annual budget was approximately $1 million. While salmon runs were steadily declining over five decades, yearly outlays increased dramatically until today's annual budget has reached a shocking $450 million, including direct and indirect costs.

The majority of these funds have been spent on hatcheries and dam modifications. In the ten years spanning 198 l-9 1, the GAO estimates expenditures of $537 million on hatcheries and $455 million on protective screens and bypass systems.' (See Fig. 1)

It would seem that the collective wisdom of the time was "If we solve the problems posed by dams, we solve the salmon problem.'*

So, how did this enormous, 50-year investment work out?

Plainly put. it didn't work. Salmon runs that once numbered in the tens of millions have dwindled to about 1 million. Of even greater concern, the large majority of those 1 million salmon are hatchery fish. Wild spawning salmon, on which we depend for the diversity needed to sustain the species, are at less than 3% of their historic abundance.*

Today, Snake River sockeye and Chinook stocks are protected under the Endangered Species Act; 35% of the historic Columbia River salmon are extinct; 39% are at risk; only 25% are not in imminent danger. At one time, Chinook were the most abundant species in the basin. As we can see from the graph shown in Figure 2, the long-term trend

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[1] Cone, Joseph: ***A Common Fate O*** 1995, p. 192. 1992 GAO report prepared at the request of Sen. Gorton and Sen. Packwood. Figure includes Federal, state and regional expenditures in the Columbia River Basin.

* Cone, Joseph: ***A Common Fate,*** p. 56.

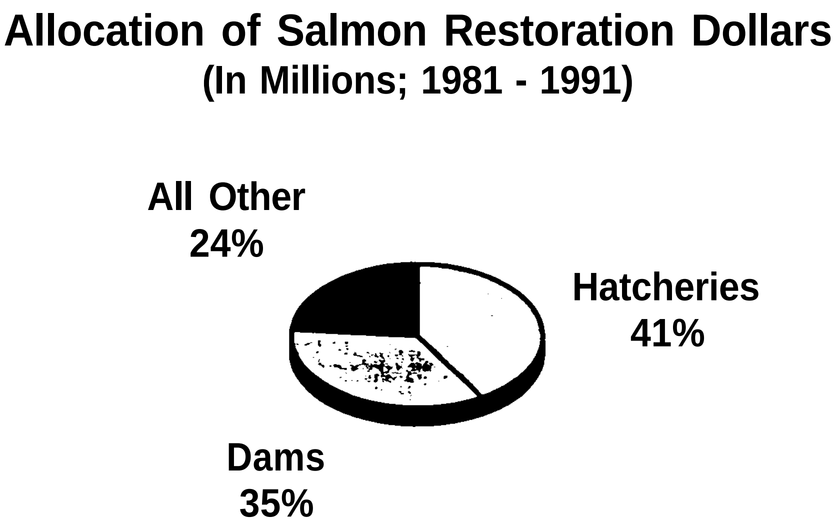


Figure 1. **Allocation of salmon restoration dollars inmillions, 1981-1991.**

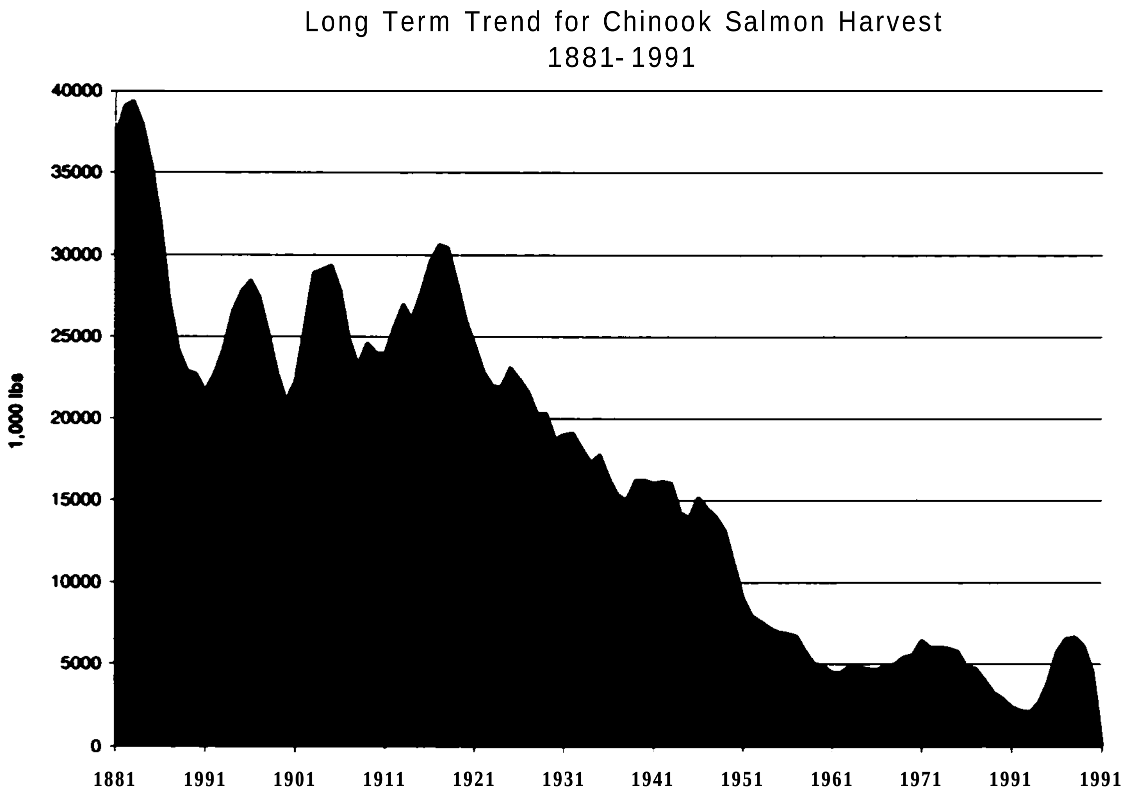


Figure 2. **Long term trend for chinook salmon harvest 1881-1981.**

for Chinook has been steadily declining since 1920.[3] All the time and money spent on hatcheries and dam modifications have failed to bring about a sustainable reverse of this decline.

All the time and money spent on hatcheries and dam modifications have failed to bring about a sustainable reverse of this decline.

In fact, by any objective measure, nearly all of the time, money and energy invested in salmon recovery to date has largely been wasted. One reason for the failure of the status quo is its reliance on applying "silver-bullet" solutions to small slices of salmon habitat and lifecycle - hatcheries attempting to circumvent incubation and fresh water rearing; passage work focusing on mainstem migration.

For the most part, these "Silver-Bullets" have been shot from the hip, without considering their physical and biological connections to the salmon's lifecycle and ecosystem requirements.

Is anyone really happy with this "status quo?" No one is getting what they want. Not the people spending the money. Not the people trying to protect the fish. And certainly not the people caught in the middle.

Can the State of Oregon really be happy with the results of their hatchery program when the cost for some stocks can exceed $500 for each surviving hatchery fish?[4]

Can the region's rate payers really be happy that the BPA spends or forgoes revenue averaging $350 million annually to help in salmon recovery, and the best we can say is - if not for that, ***matters might be worse.***

Part of the problem with the status quo lies in the fixation on issues surrounding dams, ultimately to the detriment of larger ecosystem issues such as habitat loss. Many well-informed people believe that dams are ***the primary culprit*** in the decline of salmon from their once historic abundance. But is this impression accurate? And if not, what can we do about it?

Substantial Salmon Losses Occurred Before 1940

Long before the 1940's era industrialization of the Columbia River, five decades of hard fishing, irrigation and other human activities were taking their toll on salmon. By the time the first major dam was in place, these practices had already depleted the salmon runs.

Are dams really 75% of the problem, or are other factors at work, too?

Our fixation with dams as "The Problem" is reflected in the way we spent $1.3 billion on salmon recovery from 198 1 to 199 1. Over 75% of the money went directly to dam modifications or to hatcheries which were intended to mitigate the impact of dams.[5]

An Ecosystem Strategy would ask the question, **"Are dams really 75%** of the problem, or are other factors at work, too?'

[3] ODFW, WDF 1993.

[4] Cone, Joseph: ***A Common Fate.*** p. 56.

[5] Cone, Joseph: ***A Common Fate,*** p. 192.

This is why our approach desperately needs to change. As Albert Einstein remarked:

“The significant problems we face cannot be solved by the same level of thinking that created them. ”

Clearly, it’s time to raise our level of thinking. This “higher level of thinking" is to apply an Ecosystem Strategy to the problems of salmon recovery in the Columbia River system. The principles underlying Ecosystem Strategy are nothing new. As early as 1889, Major John Wesley Powell suggested that county lines be established so that each river valley would become a political unit whose inhabitants could work cooperatively.

More recently, Freeman House wrote in ***To Learn the Things we Need to Know:***

“The first thing we learned about salmon was the importance of the watershed as a unit of perspective. If salmon organize themselves so clearly by the watershed, wouldn’t it make sense for us to organize our efforts similarly?”

Approaching the problem of salmon from an Ecosystem perspective encourages a broader outlook and dialog. No longer can one issue be defined as ‘The Problem,** such as mainstem passage has been in the past. In an Ecosystem approach, all of the factors which contribute to the problems of salmon in the Columbia basin are carefully weighed - forestry practices, grazing, farming, irrigation, road building, harvest, misuse of hatcheries, and of course, mainstem passage.

In addition, Ecosystem Strategy offers you practical solutions to the complex, seemingly impossible dilemma of balancing human needs with those of the natural world. An Ecosystem Strategy can help to prioritize projects, enhance cooperation between interested parties, avoid conflicting actions or programs and build a platform for immediate action to achieve sustainable ecosystem recovery.

Ecosystem Strategy is no “silver-bullet,” but it does address one of the primary reasons why our past efforts have failed so dramatically despite staggering sums of money and our best-intentioned efforts.

We have lacked an integrated effort that takes into account all of the factors affecting the salmon’s lifecycle.

Example: How many times has a team of biologists gone out into the field to restore a particularly productive spawning area only to have their work soon undermined by the sediment from an upstream forestry operation?

Institution Gridlock Reigns

For the Snake River salmon, this kind of Institutional Gridlock occurs frequently among the two nations. four states, 40-some federal and state regulatory agencies, and no less than four major tribal governments who lay jurisdictional claim to the salmon or their habitat. Too often, these activities of these institutions either overlap, are in direct conflict or are counterproductive to one another.

We have artificially divided up the ecosystem into units of human commerce and politics - trees, water, fish, agriculture. The resulting fragmentation has severely handicapped our institutions* ability to cope with the problems of dwindling salmon.

Since none of these 40-plus institutions will be going away anytime soon, what do we do? Sit back and let institutional gridlock reign? Continue the pattern of patchwork measures that are redundant, conflicting or counterproductive? Allow competing special interests to fight over scarce resources until there's nothing left?

Or, we can raise our level of thinking.

We can accept the challenges of adopting an Ecosystem Strategy. The potential payoffs are great. We broaden our outlook; break through the institutional gridlock; integrate our solutions into a cohesive strategy; balance the values of competing interests; and finally, we may succeed in an endeavor of immense value to future generations by saving the Columbia River salmon from extinction.

But how does an Ecosystem Strategy help you, as decision makers, to solve the problems you face today? What do we mean by Ecosystem Strategy?'

Ecosystem Strategy Defined

Ecosystem Strategy has many dimensions and defies a simple, "sound-bite" definition. One definition would be that **Ecosystem Strategy balances the needs of competing interests for renewable resources by integrating workable solutions in a way that maintains ecosystem health.**

In the case of the Columbia River system, the competition is for water. The cumulative demand for water rights from the Columbia is greater than any other river system in the world. Water for hydropower and manufacturing. Water for inland transportation. Water for irrigation and farming. Water for forestry. Water for cities and recreation. And, water for salmon.

The Problem is Not tbe Salmon. It's Ecosystem Health.

We can apply the principles of Ecosystem Strategy to help define a reasonable balance between these competing interests. From an Ecosystem perspective, the common problem our community faces is not about the salmon. ***It's about ecosystem health.*** It's about how we share our resources. The plight of the salmon is a major symptom of the core problem - natural resource management. The problem isn't ***the*** salmon **-** ***there's nothing wrong with the salmon. What we*** need to restore are the critical parts **of** the **ecosystem** in which they live or die, which includes headwaters and coastal areas as well as the mainstem.

Ecosystem Strategy recognizes that to effectively solve problems in the ecosystem, we have to think in terms of natural geographical units - watersheds and ecosystems - not in the man-made notions of distinct resource or political units.

As we have seen, the salmon ecosystem is vast and diverse. This poses an incredible challenge to identifying workable and effective solutions for salmon recovery.

<u>Steps to Ecosvstem Strategy</u>

There are seven basic steps to implementing a salmon restoration program from an ecosystem perspective. We have to:

1. Bridge gaps between institutions, regulations and programs by emphasizing cooperative solutions to common problems
2. Empower each community (watershed) to identify its own problems and select the appropriate solutions within the larger context of what is beneficial to other linked watersheds
3. Build strategies based on ecosystem science
4. Build a structure for evaluating current actions and applying new knowledge to the planning of future actions
5. Develop salmon recovery goals that ocnsider legitimate competing interests in a watershed

6. Broaden our perspective to consider all of the factors that contribute to ecosystem decline and salmon mortality
7. Develop a historical perspective for the salmon, their habitat and management institutions in a watershed

By broadening our perspective and improving coordination between institutions and interested parties, Ecosystem Strategy results in:

- A greater synergy between programs
- A reduction of inefficient spending on conflicting, redundant and ineffective programs
- More shared responsibility
- Programs tailored to local needs and problems - avoiding a "one size fits all" approach
- Greater emphasis on the long term sustainability of renewable resources

Doing Things Diierently

1. If we are to change the status quo by employing an Ecosystem Strategy, we must be prepared to do a few things differently:
2. Strive for integrated solutions. Shun simplistic ones.
3. Commit to a long-term vision and goal. Don't allow short-term crisis management to derail long-term objectives.
4. Encourage the willingness and ability to bridge institutional barriers. Discourage narrow minds and narrow focus.
5. Accept the reality that not everything is known for certain, and work with what ***is*** known. Don't allow uncertainty to become an excuse for inaction.
6. Incorporate and apply new learning as it is acquired. Don't become defensive of a single approach as being "right."
7. Accept accountability. Monitor and evaluate results.
8. Adopt a management method that incorporates and sustains these values.

Ecosystem Strategy will allow us to be better stewards of our resources while containing costs and risks. In financial terms, it may well reduce wasted expenditures by eliminating conflicting and counterproductive programs. In human terms, it requires us to choose real solutions over compromise and political window-dressing.

PRINCIPLES OF ECOSYSTEM STRATEGY

The benefits of Ecosystem Strategy should be desirable to any rational person. But, the larger question is, ***are*** they ***achievable*** in the "real world"?

The answer is "Yes," these goals are achievable, but like any other strategy, they are guiding principles which form the foundation for success.

In the implementation of an Ecosystem Strategy, we should seek to ensure that these guiding principles are met:

1. Planning and decision making occurs on regular cycles for both decision makers and their staffs.
2. Goals and objectives are well-defined.
3. Fact finding is scientific and objective.
4. ***AN*** reasonable treatment alternatives are evaluated and prioritized.
5. Selected treatment recommendations are implemented as prescribed.
6. Results are evaluated scientifically.
7. Treatment objectives and procedures are refined based on the feedback from evaluation and monitoring.

An Ecosystem Strategy that incorporates these principles has a greater opportunity for success. To consistently apply these principles, decision makers would benefit from a management tool designed for that purpose.

Ecosystem Diagnosis and Treatment

There is one such management sytem. It is called Ecosystem Diagnosis and Treatment (EDT). EDT is designed specifically to help organizations implement effective Ecosystem Strategy by installing a six-step management system to:

1. Solicit Input
2. Perform Watershed Analysis and Diagnosis
3. Analyze Treatment Alternatives
4. Select Treatments
5. Implement and Evaluate Treatments
6. Apply New Learning Gained from Monitoring and Evaluation

Let's examine each one of those points in more detail.

Step One: Solicit Input

EDT solicits input from all interested parties to compile an inventory of the affected values. The intent in this step is to inventory all of the qualitative and quantitative objectives, not to build a consensus.

Step Two: Perform Watershed Analysis and Diagnosis

EDT compares a hypothetically healthy system to current conditions. It identifies and prioritizes specific problem areas within the context of the known values and objectives.

Step Three: Analvze Treatment Alternatives

The EDT management system inventories all of the reasonable treatment alternatives. Then, it examines in detail the potential trade-offs between the treatment alternatives and the expressed objectives and values of the interested parties. As part of this process, EDT provides the scientific basis for prioritizing and selecting treatment actions.

Step Four: Select Treatments

From this analysis, decision makers select specific Treatment Recommendations with ***measurable*** goals. This step explicitly defines what results are expected and what constitutes success. Also, this phase of the EDT system clearly identifies where issues of uncertainty are, so that they may be clarified later through monitoring and evaluation.

Step Five: Implement and Evaluate Treatments

The EDT system initiates treatment actions and monitors them to determine if they have been implemented as presecribed. Futher, EDT asks:

- Have the measured results met expectations?
- Are there any unexpected results or consequences?
- What new learning has occurred? Have any points of previous uncertainty been clarified?

Step Six: Apply New Learning

EDT feeds back new learning by refining the program objectives, modifying the treatment actions and incorporating this knowledge into future planning.

The Benefits of EDT

Using the EDT management method, you can take advantage of a valuable tool to help you make more informed decisions. EDT is the management tool that allows you to capture the benefits offered by an Ecosystem Strategy:

1. By soliciting input in ***Step One. we*** bridge institutional gaps and empower local communities.
2. In performing the analysis and diagnosis of ***Step Two, we*** broaden the perspective to include all important factors. This helps to promote more shared responsibility.
3. ***Step Three*** analyzes all the Treatment Alternatives, creating synergy between programs, eliminating waste and encouraging more efficient use of financial resources.
4. Selecting specific Treatment Alternatives, as we do in ***Step Four,*** allows targeted objectives such as salmon recovery to be pursued within a larger ecosystem perspective. It also helps to avoid governmental regulations that may be inappropriate for the local conditions.
5. ***Step Five*** Implements, Measures and Evaluates Treatment Actions, using state-of-the-art science while safeguarding the long-term sustainability of renewable resources.
6. Finally, in ***Step Six,*** we build a structure for evaluating current actions and applying new knowledge by automatically feeding back the information gained from our monitoring and evaluation.

The Challenges of EDT

EDT is as much a fundamental departure from the status quo as is the Ecosystem Strategy it is designed to implement. EDT challenges decision makers to change in several important ways.

With EDT, we must be prepared to:

- Make decisions based on what represents the best solutions and resist the temptation to make compromises that value political window-dressing over results
- Revisit decisions as new knowledge is gained
- Recognize the time and complexity that comes with a true scientific approach of theory, hypotheses and testing
- Accept responsibility and accountability

SUMMATION

An Ecosystem approach is too broad a concept to be an effective strategy without a coherent management system to guide its implementation. EDT is the management tool that enables us to pursue a pragmatic and scientifically sound Ecosystem Strategy. EDT is the method by which we learn and then refine our strategy based on new knowlege.

Speaking to a group of people working on the salmon crisis, Sen. Hatfield once said:

"The future of salmon runs, the ability to sustain our current economic base, and our ability to plan for future growth will hinge on the outcome of this process. Whether you realize it or not, you are being entrusted with the preservation of our unique way of life in the Pacific Northwest for generations to come. "

Each one of us who is in a position of power or authority regarding this issue has been similarly entrusted. In the spirit of that trust, we believe it is time to raise our level of thinking and broaden our perspective. It is time to stop ignoring the obvious and begin to treat ***ecosystem problems*** on an ***ecosystem level.***

SALMON RESTORATION FROM AN ECOSYSTEM PERSPECTIVE: OVERVIEW OF AN IMPLEMENTATION STRATEGY

Presentation Notes

The purpose of this presentation is to:

- Present a brief overview of salmon restoration in the Columbia Basin;
- Briefly describe a strategy to restore salmon from an ecosystem perspective;
- Describe how the strategy would be put into practice, and;
- Describe benefits of the strategy and how it relates to the Fish and Wildlife Program.

The presentation focuses on institutional considerations rather than technical aspects of ecosystems and restoration methodology.

STATUS QUO

> President Ronald Reagan once said, ***"Status Quo. you know that is Latin for The Mess We*** 're ***In.*** " The status quo in salmon restoration illustrates why it is necessary to consider a different approach, an approach based on an ecosystem perspective.

Chinook salmon were the dominant species of Pacific salmon in the Columbia Basin and since they were the species targeted by commercial fishermen, harvest data generally reflects the long-term trend in abundance. The harvest data from 1866- 1993 show four distinct phases: the initial gearing up of the fishery, 1866 to 1888; a period of apparent stable production, 1888 to 1920; a period of decline, 1920 to 1958; and persistent depletion, 1958 to present.

The current restoration program traces its roots back to the 1940s. The initial program was projected to last 10 years and cost $20 million dollars. The program continued beyond the initial 10 years and in the first 40 years (1940 to 1980) about $495 million dollars were spent on salmon recovery. In the last ten years (198 1 to 1991), salmon recovery has cost about $1.3 billion. The costs are still increasing. The 1994 Fish and Wildlife Program estimates that annual expenditures (direct and indirect) may reach $450 million. The majority of the direct program funding has been spent on hatcheries and fish passage at the mainstem dams.

Salmon runs that once numbered in the tens of millions have dwindled to about 1 million. Of even greater concern, the large majority of those 1 million salmon are hatchery fish. Wild spawning salmon, on which we depend for the diversity needed to sustain the species are at less than 3% of their historic abundance. Today, Snake River sockeye and chinook stocks are protected under the Endangered Species Act; 35% of the historic Columbia River salmon stock are extinct; 39% are at risk; only 25% are not in imminent danger. There is no evidence of a sustained reversal of long-term decline in chinook salmon or any of the other species of Pacific salmon.

Is anyone really happy with this "status quo?" No one is getting what they want. Not the people spending the money. Not the people trying to protect the fish. And certainly not the people caught in the middle — the general public. One reason for the status quo is the history of reliance on "silver-bullet" solutions to small slices of salmon habitat and life cycle — hatcheries attempted to circumvent habitat problems; passage work focused on mainstem migration. Hatchery production and mainstem passage are important elements in any recovery plan but they must be embedded in a broader context, an ecosystem context.

> As Albert Einstein remarked, ***"The significant problems we face cannot be solved by the same level of thinking that created them."***

Clearly, there is a need for a change in approach, a change that is holistic and approaches the problems of salmon from an ecosystem perspective. This will require technical and institutional realignment in our approach to salmon recovery. The need for a different approach is reflected in the 1994 Fish and Wildlife Program which contains language that recognizes the importance of an ecosystem perspective.

Approaching the problem of salmon from an ecosystem perspective encourages a broader outlook and dialogue. No longer can "The Problem," be defined as one or two issues such as mainstem passage or survival of hatchery fish. In an ecosystem approach, all of the factors which contribute to the problems of salmon in the Columbia Basin — forestry practices, grazing, farming, irrigation, road building, harvest, misuse of hatcheries, and mainstem passage — are carefully weighed in a holistic context.

THE PROBLEM IS NOT THE SALMON

The common problem the region faces is not really about salmon, although the salmon's condition is an important symptom of the problem. It's about the water and more generally, it's about the health of the Columbia ecosystem. It's about how we share the resources of the Columbia ecosystem. The plight of the salmon is a symptom of the core problem — a degradation of healthy ecosystem function. The problem is a degradation in the critical parts of the ecosystem in which the salmon live or die, including headwaters and coastal areas as well as the mainstem. To effectively solve the problems and restore salmon productivity we have to think in terms of natural geographical units — watersheds or ecosystems.

When we focus on human economic or regulatory institutions or political units instead of natural units our perspective is narrowed and fragmented along artificial institutional boundaries. This is not a small problem. For the Snake River salmon, two countries, 6 states, 40-plus federal and state regulatory agencies, and no less than four major tribal governments claim jurisdiction over the salmon or their habitat. Too often, the activities of those institutions overlap, are in direct conflict or are counterproductive to one another. We have artificially divided up the ecosystem into units of human commerce and politics — trees, water, fish and agriculture. The resulting fragmentation has severely handicapped our ability to cope with the problems of dwindling salmon. None of the 40-plus institutions will be going away anytime soon, so what do we do? Sit back and let institutional gridlock reign? Continue the pattern of patchwork measures that are redundant, conflicting or counterproductive? Allow competing special interests to fight over scarce resources until there's nothing left?

We can accept an alternative and begin taking the first small steps toward a realignment of our approach to salmon recovery, a realignment that will bring us closer to an ecosystem perspective. The potential payoffs are great. We broaden our outlook; dissolve the artificial institutional barriers; integrate solutions into a cohesive strategy that recognizes and balances the values of competing interests; and finally, we may succeed in producing something of immense value to future generations by giving the Columbia River salmon a healthy connected habitat.

WHAT ARE THE BASIC CONCEPTS

Ecosystem strategy • Watershed planning should employ a holistic approach that incorporates human economies and values. The strategy should incorporate the broad range of values and objectives that are important to the concerned citizens in a watershed while recognizing that any group of citizens will contain a diverse set of values. Although, salmon are the catalyst that brings these interests together, the purpose and benefits of watershed planning are much broader. The salmon may be viewed as an indicator, or a diagnostic, of the condition of a watershed. The concern is not just over the loss of the salmon itself but also over what its demise might portend for other economic or esthetic qualities of the environment in a watershed.

Responsive management • Management should be responsive to new information, often referred to as adaptive management. Adaptive management allows action in the face of scientific uncertainty. Adaptive management serves two important functions. It assures the management of the ecosystem is progressive, that we continue those actions that are effective and discontinue those that prove ineffective or damaging. It also provides the means for an open decision making process, where the public has the opportunity to remain informed and therefore participate effectively.

Sustainability • The concept of sustainability encompasses the idea that the values and objectives we want to achieve for the watershed should not be transient. We associate sustainability with ecosystem health. Salmon have varying habitat requirements throughout their life cycle and through their extended ecosystem from headwaters to the ocean. A system that can meet all the requirements of the salmon life cycle is likely to possess some of the important qualities needed for sustainability of other values as well. There is a general rule of thumb that applies here. Solutions to problems of salmon production that are ecologically sound will radiate secondary benefits throughout the ecosystem.

Scientific method • The final premise is the adherence to the scientific method of inquiry. Fundamental to the scientific method is the existence of an explicit framework within which we can organize information about the system we are trying to understand and manage. The framework describes logical linkages between actions and events within the watershed and their effect on values and objectives. Such a framework is a central part of the Ecosystem Diagnosis and Treatment (EDT) approach discussed later.

HOW IS RESTORATION FROM AN ECOSYSTEM PERSPECTIVE IMPLEMENTED?

1. We have to bridge the gaps among economic and regulatory institutions, and restoration programs emphasizing cooperative solutions to common problems.
2. We have to empower each community (watershed) to identify its own problems and select the appropriate solutions, within the huger context of what is beneficial to other linked watersheds.
3. We have to build strategies based on ecosystem science.
4. We have to build a structure for evaluating current actions and applying new knowledge to the planning of future actions.
5. We have to develop salmon recovery goals that consider legitimate competing interests in a watershed.
6. We have to broaden our perspective to consider all of the factors that contribute to ecosystem decline and salmon mortality.
7. We need to develop a historical perspective for the salmon, their habitat and management institutions in a watershed.

SLIDES

BENEFITS

Approaching the recovery of Pacific salmon from and ecosystem perspective gives:

- A greater synergy between elements in restoration programs and between economic interests in a basin.
- A reduction in inefficient spending on conflicting, redundant and ineffective programs.
- More shared responsibility.
- Programs tailored to local needs and problems – it avoids the one size fits all approach.
- Greater emphasis on the long term sustainability of renewable resources.

DOING THINGS DIFFERENTLY

If we are to change the status quo by employing an ecosystem strategy, we must be prepared to do a few things differently:

1. Strive for integrated solutions. Shun simplistic ones.
2. Commit to a long-term vision and goal. Don't allow short-term crisis management to derail long-term objectives.

3. Encourage the willingness and ability to bridge institutional barriers.
4. Discourage narrow minds and narrow focus.
5. Accept the reality that not everything is known for certain, and work with what ***is*** known in an adaptive process. Don't allow uncertainty to become an excuse for inaction.
6. Incorporate and apply new learning as it is acquired. Don't become defensive of a single approach.
7. Accept accountability. Monitor and evaluate results.
8. Adopt a management method that incorporates these activities.

An ecosystem perspective will allow us to be better stewards of our resources while containing costs and risks. In financial terms, it could reduce wasted expenditures by eliminating conflicting and counterproductive programs- In human terms, it requires a choice between real solutions and political window-dressing. It also requires that we work with a set of principles.

PRINCIPLES OF RESTORATION PLANNING AND IMPLEMENTATION

1. Planning and decision making occurs on regular cycles for both decision makers and their staffs.
2. Goals and objectives are well-defined.
3. Fact finding is scientific and objective.
4. *AI1* reasonable treatment alternatives are evaluated and prioritized.
5. Selected treatment recommendations are implemented as prescribed.
6. Results of treatments are evaluated scientifically.
7. Treatment objectives and procedures are refined based on the feedback from evaluation and monitoring.

A restoration program that incorporates these principles has a greater opportunity for success. To consistently apply these principles, decision makers will benefit from a management tool designed for that purpose. EDT is one tool that fills that need.

EDT OVERVIEW

EDT is designed specifically to help organizations plan and implement effective restoration programs by installing a six-step management system to:

1. Solicit input.
2. Perform analysis and diagnosis.
3. Analyze treatment alternatives.
4. Select treatment actions.

5. Implement and evaluate treatment actions.
6. Apply new learning gained from monitoring and evaluation.

EDT SOLICITS INPUT

EDT solicits input from all interested parties to compile an inventory of the affected values. The intent in this step is to inventory all the qualitative and quantitative objectives, not to build a consensus.

EDT PERFORMS ANALYSIS AND DIAGNOSIS

EDT compares a hypothetical healthy system to current conditions. It identifies and prioritizes specific problem areas within the context of the known values and objectives.

EDT ANALYZES TREATMENT ALTERNATIVES

The EDT management system inventories all of the reasonable treatment alternatives. Then, it examines in detail the potential trade-offs between the treatment alternatives relative to the expressed objectives and values of the interested parties. As part of this process, EDT provides the scientific basis for prioritizing and selecting treatment actions.

EDT SELECT TREATMENT ACTIONS

From this analysis, decision makers select specific treatment recommendations with ***measurable*** goals. This step explicitly defines what results are expected and what constitutes success. Also, this phase of the EDT identities where issues of uncertainty are, so that they may be clarified later through monitoring and evaluation.

EDT IMPLEMENTS AND EVALUATES TREATMENT ACTIONS

The EDT monitors treatment actions to answer these questions:

- Have the measured results met expectations?
- Are there any unexpected results or consequences?
- What new learning has occurded? Have any points of previous uncertainty been clarified?

EDT APPLIES NEW LEARNING

EDT uses new learning to refine program objectives, modify treatment actions and incorporate this knowledge into future planning.

EDT BENEFITS

EDT has the potential to provide the following benefits:

1. By soliciting input in Step 1, institutional barriers are dissolved and local communities are empowered to identify solutions appropriate to their problems.

2. In performing the analysis and diagnosis of Step 2, we broaden the perspective to include all important factors. This helps to promote more shared responsibility and help create synergy among programs.
3. Step 3 analyzes all the treatment alternatives which helps eliminate waste and encourages more efficient use of financial resources.
4. Selecting specific treatment alternatives involves a careful weighing of risks (Step 4).
5. Step 5 implements, measures and evaluates treatment actions, utilizing state-of-the-art science.
6. Finally, Step 6, we build a structure for evaluating current actions and applying new knowledge by automatically feeding back the information gained from our monitoring and evaluation.

IS THIS APPROACH COMPATIBLE WITH THE FISH AND WILDLIFE PROGRAM?

The EDT process is compatible with the increased emphasis on an ecosystem perspective contained in the 1994 Fish and Wildlife Program. For example, section 2.1A. 1 of the program states: ***Explore methods to assess trends in ecosystem health. . . . If found feasible, this assessment will result in a periodic report on the ecological health of the Columbia River Basin.*** (emphasis added)

The EDT paper published in fisheries provides a basis for developing key indices of ecosystem health, especially those relevant to Pacific salmon. There are several other areas/measures in the 1994 Fish and Wildlife Program where the EDT process would prove useful to managers who want to implement program measures within an ecosystem perspective.

The Council recognized that the EDT process is a work in progress and requested further development (Section 7.3A. 1). The next step in this development is to expand its applicability to a complete watershed or ecosystem. The tools and analytical procedures can now be developed that let us to take advantage of the EDT framework in the integration of subbasin, mainstem Columbia (and Snake), estuary, and ocean subsystems. There are several subbasins that would be suitable as focal points for this kind of project, where a broad range of current and historic information is available. In this regard, it is important to remember that the ecosystem of salmon that spawn in those subbasins includes the mainstem Columbia river, the estuary and ocean. Each of these subunits of the ecosystem must be considered, although the intensity of the analysis will vary among subunits.

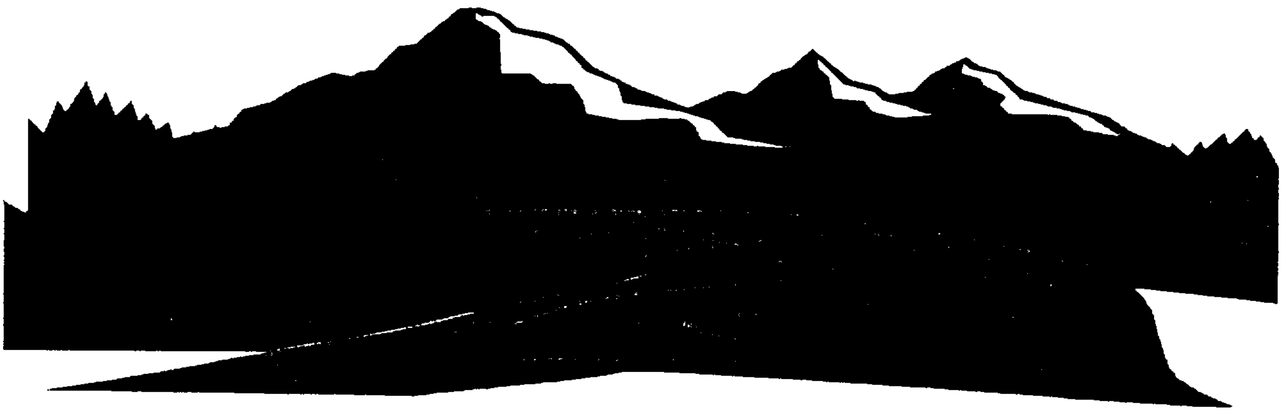
The EDT is an architecture around which a new and comprehensive understanding of the Columbia Basin ecosystem can be constructed. Its architecture is robust enough to also take into consideration values other than salmon.

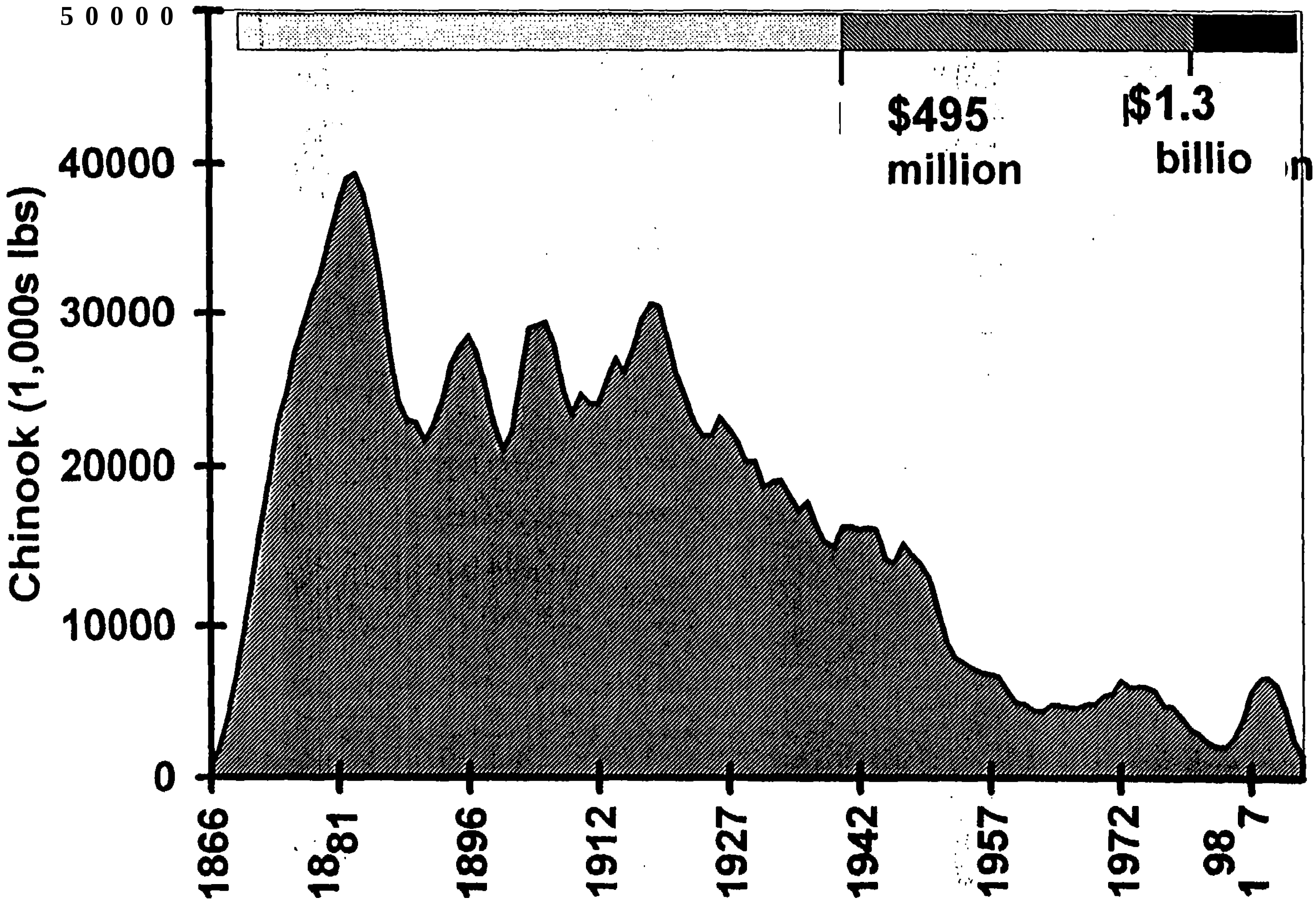
APPENDIX

SALMON RESTORATION FROM AN ECOSYSTEM PERSPECTIVE

Overview of an Implementation Strategy

May 1995

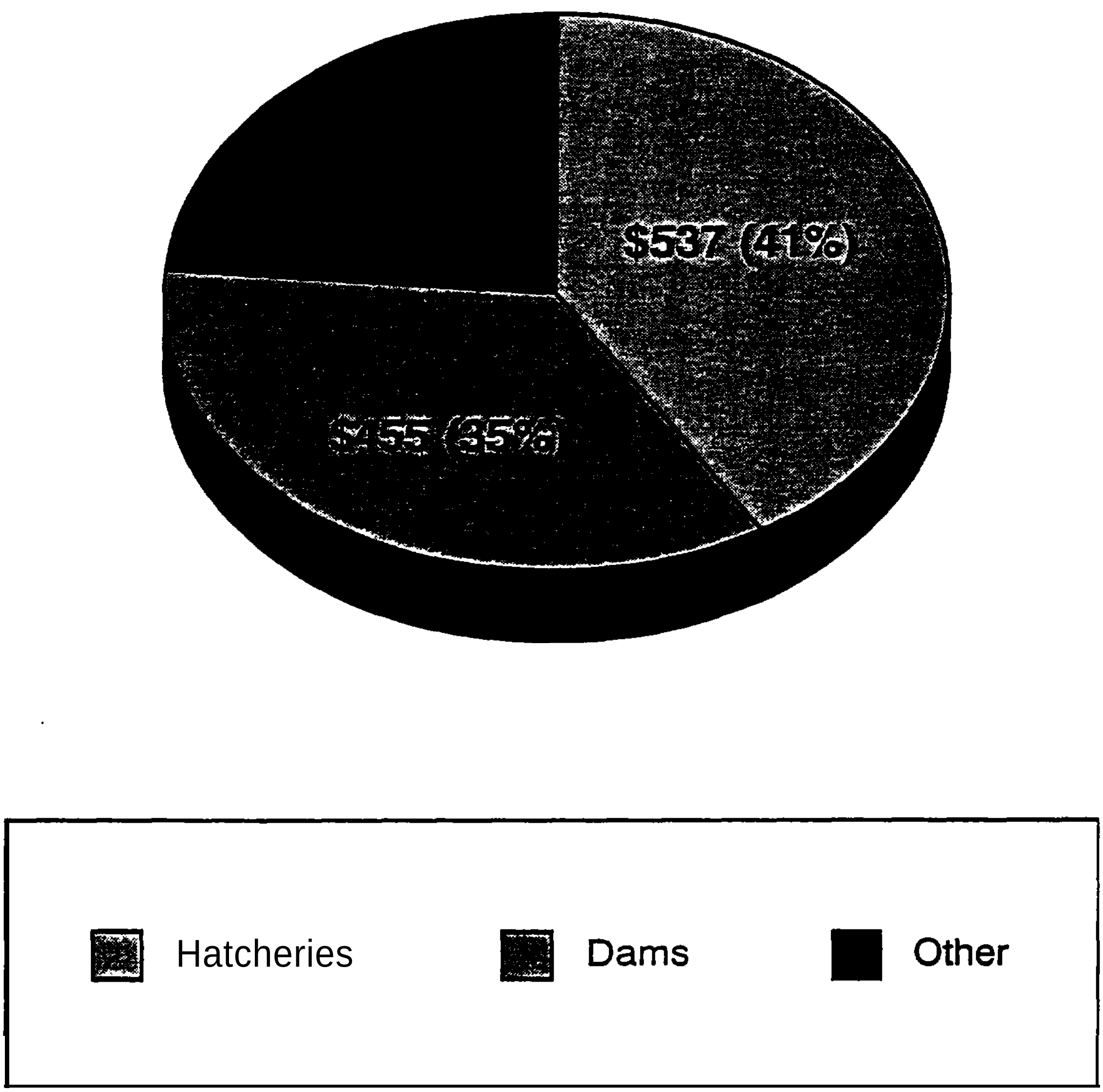




Five year moving average of chinook salmon harvest in the Columbia River and total expenditures for salmon recowry 1940 to 1980, 1881 to 1991.

ALLOCATION OF **SALMON** RESTORATION DOLLARS

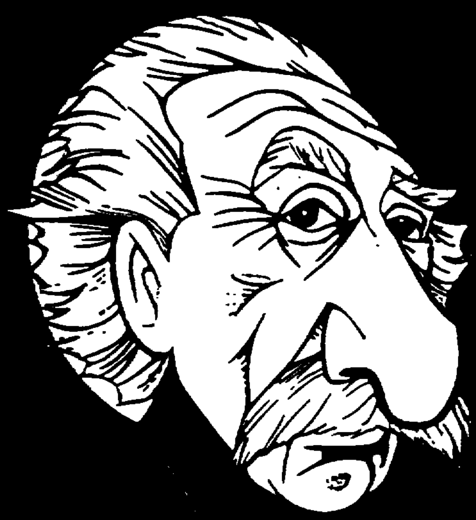
(in Millions; 1981-1991)



Source: GAO

"The significant problems we face cannot be solved by the same level of thinking that created them."

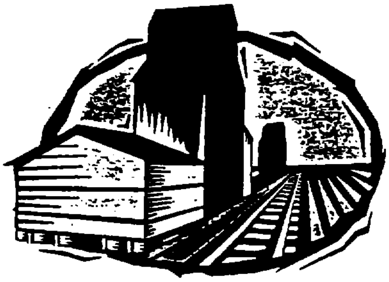
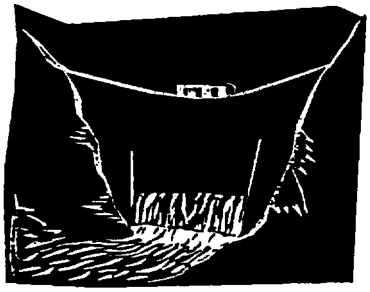
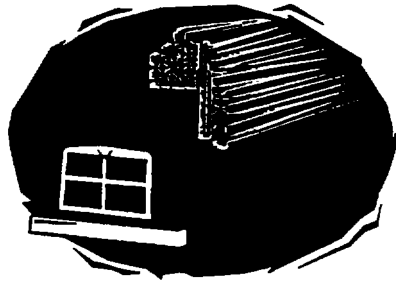
–Albert Einstein



IT'S TIME FOR A HIGHER LEVEL OF THINKING,

IT'S TIME FOR ECOSYSTEM SOLUTIONS

TO ECOSYSTEM PROBLEMS,

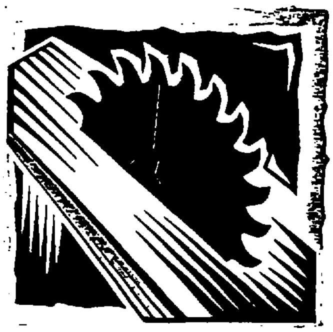




ECOSYSTEM STRATEGY...

balances the needs of competing interests for renewable resources by integrating workable solutions in a way that maintains ecosystem health

IT’S NOT ABOUT SALMON, IT’S ABOUT ECOSYSTEM HEALTH.

Competing Interests for Columbia River Basin Resources

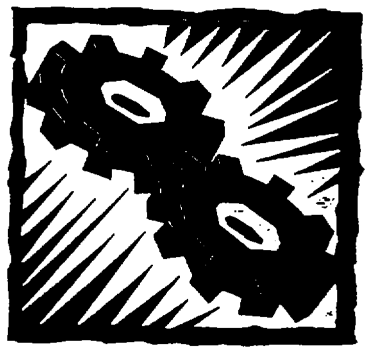


Forestry & Lumber Mills

Ranching

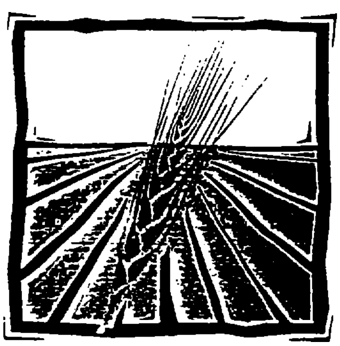
Hydropower

Inland Transportation

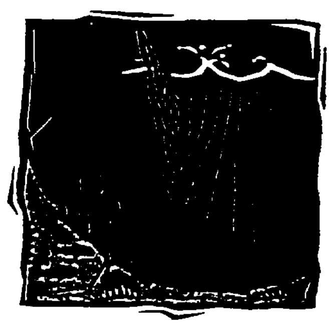


Industry & Manufacturing

Recreation

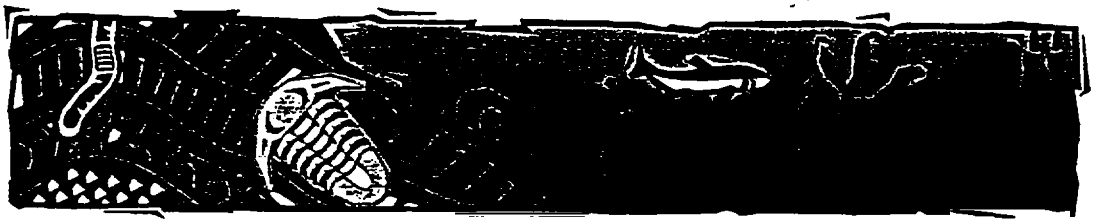


Farming & Irrigation



Commercial Fishing

THE PRINCIPLES OF ECOSYSTEM STRATEGY



1. Planning and decision making occur on regular cycles

2. Goals and objectives are well-defined

3. Fact finding is scientific and objective

4. All reasonable treatment alternatives are evaluated and prioritized

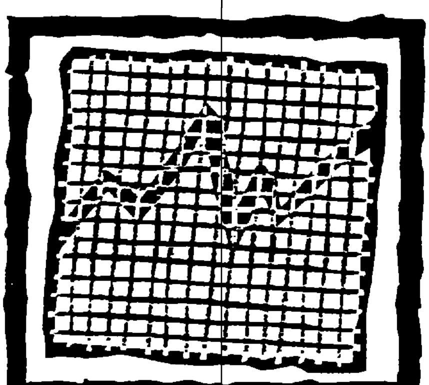
5. Selected treatment recommendations are implemented as prescribed

6. Results are evaluated scientifically

7. Objectives and procedures are refined based on feedback

THE BENEFITS OF ECOSYSTEM STRATEGY

- Greater integration and synergy- between programs
- Reduction of inefficient and wasteful spending
- More shared responsibility
- Programs tailored to local needs and problems
- Greater emphasis on long-term sustainability of renewable resources



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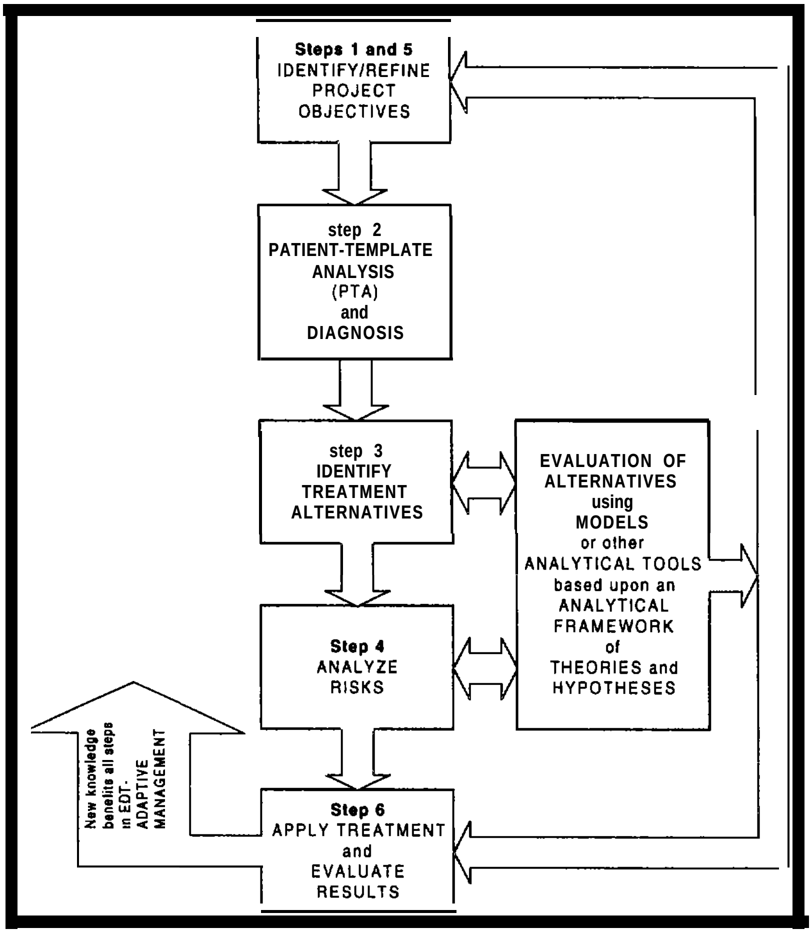

An Approach to the Diagnosis and Treatment of Depleted Pacific Salmon Populations in Pacific Northwest Watersheds*

January 1995

Prepared by

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Lars E. Mobrand
Lawrence C. Lestelle
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ABSTRACT

We propose an approach to the development of restoration programs for Pacific anadromous salmon that recognizes the importance of an ecosystem perspective. Important concepts such as habitat complexity and self organizing capacity of the stock are reviewed. A planning process comprised of six steps is described. The approach includes a comparison of historic and current habitat complexity and connectivity and intrapopulation life history diversity. Uncertainties are incorporated into the planning process through assumptions which are clearly identified. Risk of project failure is determined through a qualitative or quantitative weighing of the critical uncertainties. We emphasize the concept that restoration planning is an iterative process that must be continued after implementation.

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LIST OF FIGURES

An Approach to the Diagnosis and Treatment of Depleted Pacific Salmon Populations in Pacific Northwest Watersheds

This paper proposes an approach to restoration planning that focuses on the Pacific salmon while retaining a broader ecosystem context. Our intent is to contribute to the mix of ideas and scientific debate that should be a part of the development of an ecosystem perspective for the management of Pacific salmon in watersheds of the Pacific Northwest.

The abundance of Pacific salmon (Oncorhvnchus spp.) in the Northwestern United States has declined to historic lows, and numerous stocks are threatened with extinction throughout large segments of their historic range (Nehlsen et al. 1991; Anderson 1993). Four stocks, Redfish Lake sockeye salmon (O.nerka), Snake River spring/summer and fall chinook salmon (0. tshawvtscha) and Sacramento River winter run chinook salmon, are protected under the Endangered Species Act. Petitions for other stocks are being reviewed including a coastwide petition for coho salmon (0. kisutch). The declines have forced management agencies to place more program emphasis on protection and restoration of anadromous species. Major salmon rebuilding programs are being planned and implemented in Oregon (Potter 1992). Washington (Washington Department of Fisheries (WDF) 1992; WDF et al. 1993), and Idaho (Bowles and Leitzinger 1991). Efforts in the Columbia Basin (Northwest Power Planning Council (NPPC) 1987 and 1992) may represent the largest fishery restoration program ever undertaken. Current efforts to diagnose and treat depleted salmon populations are challenging the efficacy of traditional approaches (Regional Assessment of Supplementation Project (RASP) 1992; Snake River Salmon Recovery Team (SRSRT) 1993; Lawson 1993).

The need to approach restoration and management of renewable resources from an ecosystem perspective is an emerging theme (Nehlsen et al. 1991; Doppelt et al. 1993; SRSRT 1993). The current situation appears consistent with the general observation that paradigm shifts take place during crisis (Kuhn 1970). The current switch in management emphasis from single species populations to ecosystems (Potter 1992) is the beginning of a paradigm shift (RASP 1992) brought on by continuing declines in salmon production and increasing numbers of petitions to list salmon stocks as threatened or endangered. As a result, salmon management is embroiled in a crisis. Confounded with the technical issues of restoration is a shift in societal values. In their attempt to manage renewable resources (such as fish) for the production of commodities, managers must now accommodate a growing emphasis on sustainability and biodiversity (Franklin 1992).

The task of converting the concept of ecosystem management into technical prescriptions within an institutional framework capable of implementing the prescriptions is far from complete (M. A. Shannon and C. Robinson, Institutional strategies for landscape management. Unpublished manuscript, Institute for Resources in Society, College of Forest Resources, University of Washington, 1993). In the development of institutional and technical methods for ecosystem management, the exploration of multiple approaches has value (Smith 1994). The methods we describe here extend the strategic concepts described by Doppelt et al. (1993) and Smith (1994) to tactical prescriptions. We describe a bridge between strategic theory and implementation of specific actions to restore Pacific salmon.

Although we recognize the growing emphasis on the management of whole ecosystems or watersheds, the approach described in this paper should not be confused with ecosystem management or restoration. We focus on a single species group, the Pacific anadromous salmon. However, the procedure we describe is designed to be consistent with a more inclusive program of restoration from an ecosystem perspective.

BACKGROUND

Historically, restoration of Pacific salmon focused on four approaches: (1) maintain production in freshwater through hatcheries; (2) modify specific stream habitats with fences, log weirs, and other physical structures; (3) provide minimum stream flows; and (4) reduce harvest rates to increase spawning escapements. Because these activities were carried out largely independent of any ecological context at the watershed level, they failed at best to keep up with the degradation of freshwater ecosystems and prevent continued decline, or at worst to have unintentionally contributed to both.

Recently, restoration planners have proposed a new rebuilding objective for hatcheries. Instead of circumventing degraded habitat, hatcheries should be used to restore natural production. This use of hatcheries, called supplementation, accounts for 50% of the planned increases in salmon production in the Columbia Basin (RASP 1992). The approach to salmon restoration described in this paper originally was developed to address long-standing concerns regarding supplementation and help managers plan supplementation projects.

Supplementation is "the use of artificial propagation in an attempt to maintain or increase natural production while maintaining the long term fitness of the target population, and keeping the ecological and genetic impacts on nontarget populations within specified biological limits" (RASP 1992: 6). According to this definition, supplementation shares a common principle objective with habitat restoration, i.e., the recovery of natural production. Because habitat restoration and supplementation share a common objective, the method we describe has broad relevance to the design of salmon restoration programs.

IMPORTANT CONCEPTS IN RESTORATION PLANNING

Ecosystem Health

The recent emphasis on the ecosystem or watershed as the management unit has stimulated discussion of what constitutes a healthy ecosystem (Rapport et al. 1985; Costanza et al. 1992; Doppelt et al. 1993). There are no simple, universal tests to determine the health of a watershed although general indications of stress at the ecosystem level have been proposed (Rapport et al. 1985; Rapport 1989). Ecosystem health must be determined individually for each watershed (Haskell et al. 1992), and to a large degree the assessments are qualitative (Rapport et al. 1985; Ehrenfeld 1993). A general definition of ecosystem health is the maintenance of complexity and the selfBorganizing capacity of the system (Norton 1992).

Restoration planning for Pacific salmon must recognize the broader aspects of ecosystem health while maintaining a focus on the primary objective, which is to increase production and productivity of a particular salmonid population or community. To focus on salmon while retaining an ecosystem context, we define complexity and self organization in terms specific to the salmon's habitat and life history.

Habitat Complexity

Riverine ecosystems are comprised of smaller streams and tributaries directly influenced by riparian vegetation, the larger alluvial channel influenced by the flood plain, and the estuarine and nearshore ocean influenced by the land margin (Regier et al. 1989; Simenstad et al. 1992). All of the watershed features have biological, chemical and physical connections and they are embedded in a social environment. In total these features comprise a natural cultural system. The habitat of salmon is embedded in and determined by the environment of the natural-cultural system (Warren 1979; Warren and Liss 1980). With regard to salmon habitat, complexity is the distribution and abundance of habitat types (e.g., Bisson et al. 1981) and their connectivity throughout the salmon's range.

A major consequence of land management practices and development in the riparian zone, flood plain and land margins has been the simplification and fragmentation of fish habitat (Reeves and Sedell 1992). Simplification is a reduction in the number and kinds of habitat types, a decrease in structural materials that comprise salmon habitat such as large woody debris, and declining indicators of water quality such as temperature (McIntosh et al. 1993). The simplification of riparian/stream ecosystems began shortly after the Euroamerican settlement of the Northwest (Sedell and Luchessa 198 1). In recent years (1940B 1990), simplification has continued in some rivers whereas, some streams have shown evidence of habitat recovery (B. A. McIntosh, Oregon State University, Unpublished M. S. Thesis 1992; McIntosh et al. 1993; J. E. Smith, University of Washington, Unpublished M. S. Thesis 1993).

Because of their extensive migrations in marine and freshwater, Pacific salmon inhabit a vast ecosystem comprised of a chain of favorable geographic places and a seasonal distribution appropriate for the use of those places (Thompson 1959). Habitat simplification reduces the number of favorable habitat types, and fragmentation disrupts connectivity, the ability to migrate at the appropriate time between links in the habitat chain. Even where favorable habitats are retained in undeveloped portions of watersheds, fragmentation can restrict temporal connectivity among habitats, constrain salmon use of those habitats, and restrict the expression of life history diversity. The cumulative effects of human activities in a watershed can render the lower reaches of tributary streams inhospitable because of thermal barriers, loss of suitable habitat, or restricted flow. The loss of connectivity between tributary and mainstem isolates juveniles rearing in the upper reaches of the tributary and eliminates life history opportunities. For example, irrigation diversions, loss of riparian cover and channel modification have elevated stream temperatures in the lower Yakima River to lethal levels. Historically juvenile chinook salmon migrated through the lower river during the summer months. That life history pattern has been eliminated (Watson 1992).

Self Organization

The self-organizing capacity of a salmon population is a function of the exchange of genetic information between generations and the capacity to express that information through life history diversity within a complex habitat. Regier et al. (1989) suggest that ecological self organization is an important structural element of the ecosystem that needs to be addressed in watershed level restoration. They also suggest that one way to consider self-organizing capacity of a system is through information exchange at reproduction. Effective exchange of genetic information at reproduction is dependent on three elements: a degree of reproductive isolation, sufficient numbers to avoid inbreeding, and sufficient habitat quality in spawning areas to permit survival through incubation.

Life history diversity in anadromous salmon is the variable (time and space) use of the chain of rearing and migrating habitats. Diverse life history patterns dampen the risk of extinction or reduced production in fluctuating environments (Den Boer 1968). Salmon must contend with annual fluctuations in climate, as well as long-term climate cycles. In addition, the physical habitat of rivers is subject to natural disturbance through landslides, fire, and channel shifts during floods.

Timing of the use of habitats is a life history trait important to the persistence of salmon populations, and evidence exists for genetic control over juvenile and adult migration timing (Carl and Healey 1984; Gharrett and Smoker 1993). The potential and realized life histories of a stock theoretically reflect its adaptive capacityCthe ability to survive in fluctuating environments (M. J. Weavers, Oregon State University, Unpublished Ph.D. Thesis, 1993).

Intrapopulation life history diversity has been studied in the past few decades. Reimers (1973) and Schluchter and Lichatowich (1977) identify multiple life histories of chinook salmon from the Sixes and Rogue rivers in Oregon. The life histories exhibit different patterns of habitat use and survival to adult. Chinook salmon in the Nanaimo River, British Columbia, exhibit three life history patterns. Those life histories appear to be genetically isolated adaptations to rearing environments (Carl and Healey 1984).

Life history diversity should be considered in the design of enhancement programs (Carl and Healey 1984). Nickelson et al, (1986) report a mismatch between life history and habitat that negated attempts to restore natural production through hatchery supplementation of coho salmon in Oregon's coastal streams. Reproductive success of the hatchery fish was reduced because they spawned too early to avoid mortality caused by the normal occurrence of freshets in supplemented streams.

Juvenile coho salmon in the Queets River, Washington, exhibit multiple life histories with different smolt production characteristics (Lestelle et al. 1993).

Pink salmon (O. gorbuscha) superficially exhibit the least diverse life history pattern among anadromous Pacific salmon. All pink salmon mature at age 2 and freshwater residence is minimal. The juveniles migrate to sea shortly after emergence (Heard 199 1). However, pink salmon in a small stream C Auke Creek (350 m), a tributary to Auke Bay, Alaska C exhibit a complex population structure and diverse life history, including five subpopulations characterized by the time and place of spawning (Gharrett and Smoker 1993). Migration timing in those life histories had a genetic component (Gharrett and Smoker 1993).

The general observation by Thompson (1959) that salmon life histories are comprised of a chain of habitats with a favorable spatial/temporal distribution is being confirmed by contemporary observations of life history diversity within stocks and watersheds. The spatial/temporal diversity of life histories expressed within a complex habitat structure is an important determinant of productivity and self-organizing capacity in Pacific salmon. Restoration should focus on rebuilding the productive life history-habitat relationships and the conservation of diverse life histories.

Historical Reconstruction

Programs designed to improve natural production of salmon usually include a comparative analysis of the historic and current abundance of the target population. The depth of this analysis varies and is often limited to production data (harvest or escapement). Rarely does it include analysis of historical habitat quality or life history diversity because these data are limited or not available. Analysis of abundance usually does not reflect predevelopment conditions that governed abundance. The Northwest Power Planning Council's (NPPC) report on salmon and steelhead losses in the Columbia River is an exception (NPPC 1986). Managers are reluctant to conduct extensive historical reconstruction because it usually includes speculation and debate (NPPC 1986). Some reluctance stems from the recognition that many pristine habitats and salmonid populations have been irreversibly degraded. It is assumed that little can be gained from extensive consideration of historical habitats that cannot be rehabilitated (WDF et al. 1993) or where current potential production cannot be equated to historic production (Nickelson et al. 1992).

Ecosystem condition is a product of history (Lewis 1969). Ecosystems supporting Pacific salmon are the product of the geologic history of the watershed, the erosional history of the river and its surrounding land forms, the evolutionary history of the biotic community, and the cultural history of human economies that exploited and altered the ecosystem. The histories that produced a system's current state also influence and constrain its future development trajectory. An understanding of the past conditions of streams and the processes that have changed salmon habitat is critical to the diagnosis and treatment of depleted salmon populations. However, the importance of historic reconstruction is often underestimated (Williams 1993). Wild stocks of salmon have adapted to local habitats and environmental conditions. Restoring the productive capacity of the watershed requires an understanding of the historical nature of stream habitats to which native salmon populations have adapted (Sedell and Luchessa 198 1). To obtain that understanding a description of undisturbed habitat conditions should be completed and included in restoration plans (Doppelt et al. 1993).

Descriptive reconstruction of historical habitats should be undertaken to help explain current observations that are the outcome of past processes. Current conditions are a consequence of the interaction of a progression of human activities and technologies applied to ecosystems. The sequence of events leading to this degradation in a watershed will not be repeated. We will never again see the low-elevation reaches of coastal watersheds dominated by old growth forests. Technology changes the pattern and rate of resource exploitation and habitat degradation in a watershed. In addition, the human population is persistently growing. Consequently reconstruction often takes the form of a historical narrative that cannot always be experimentally verified (Sauer 1952; Mayr 1982), although reconstruction can provide the basis for forming a hypothesis that can be tested (Mayr 1982) through a well designed restoration program. In an important sense, the specific treatments selected for a salmon population or a watershed are a test of hypotheses derived from the reconstruction of historical conditions.

From the preceding discussion, it should be clear that restoration does not imply a return to pristine conditions. Restoration is the return of that part of the historic habitat quality and production of salmon that is possible within existing biological and social constraints.

Uncertainty and Riik

In restoration planning, what we don't know is often as important in shaping the program as what we do know. Critical information about the historic and current relationships among habitat, life history and production in stream ecosystems is usually missing. Consequently, management decisions-whether to initiate treatments or take no action-are made with uncertainty. This automatically presents the manager with risk-risk of failure and risk of surprise outcomes.

History gives examples of managed systems that were damaged because of a failure to recognize and respond properly to the unexpected (Timmerman 1986). The collapse of hatchery coho production in the Oregon Production Index and the subsequent overharvest of natural stocks are examples of failures to provide a timely, effective response to surprise events. In fisheries, surprise might express itself as a shift to a new stability domain (e.g., Peterman 1977) or "flip flop," where species change dominance and switch their response to environmental changes (e.g., Daan 1980; Skud 1982). Surprise can originate from natural oscillations in productivity (e.g., Ware and Thomson 1991), the causes of which have not been identified and accounted for in restoration planning. The interaction between natural production cycles and habitat degradation can lead to misinterpreting the effect of rebuilding programs, if the nature of the oscillation is not known or properly taken into account (Lawson 1993).

Unexpected events should be reduced through a careful review of the historical record and reconstruction of predevelopment habitats and life histories. However, even when restoration planning includes historical analysis, surprise is still a possibility that must be considered. Monitoring and evaluation must be designed to give early warning of unintended effects of recovery programs.

GUIDELINES FOR DIAGNOSIS AND TREATMENT PROCEDURES

The guidelines presented here are not rules to be followed in every detail. Their purpose is to guide the development of restoration plans by stimulating the manager to think about the structure and function of the ecosystem supporting the salmon population to be restored. Managers are encouraged to adapt these guidelines to the specific conditions of the watershed, stock of salmon, **and** management objectives.

All of the information called for in the guidelines need not be in hand before a project is implemented. Managers should assemble and analyze existing information. Uncertainties due to missing information must be identified and their effect on recovery of the target salmonid population accounted for through reasonable assumptions or hypotheses. The decision to proceed is based on an assessment of the risk-where risk is the likelihood of failure to achieve plan objectives. Monitoring and evaluation (M& E) must be carefully designed to reduce information gaps, uncertainty, and risk and to learn from the specific actions taken. While this approach allows projects to be implemented with information gaps and uncertainty, it also means that planning and evaluation become an iterative process. New information is used to update the plan until objectives are achieved. The entire process is consistent with the concept of adaptive management described by Walters (1986) and Lee (1993).

The concepts discussed in the previous section were incorporated into six steps comprising the development and implementation of a restoration plan for salmonid populations (Figure 1). Steps 1 and 5 establish and refine the goal. Step 2 is factBfinding and analytical. Steps 3 and 4 identify and evaluate alternative restoration strategies. Step 6 is implementation, and M & E.

Identify Existing Management Objectives (Step 1)

Every major river or subbasin in the Pacific Northwest has at least generalized salmon management objectives (escapement targets or harvest goals) contained in statewide management plans. In addition, management objectives for specific subbasins are found in individual subbasin plans in the Columbia Basin, hatchery master plans, and regional, district, or tribal planning documents. Where they have not been explicitly stated through the above documents, management objectives might be inferred from harvest regulations, stocking programs, agency comments on forest practice applications, environmental impact statements, or water quality and land use regulations.

Management objectives generally have been limited to numerical targets stated as the number of juveniles released from a hatchery or the expected number of adults in the catch and escapement. Numerical targets are important components of objectives and are significant measures of performance. However, to ensure sustainable restoration, numerical targets must be conditioned by specifications of resource quality (Regier and Baskerville 1986). Where hatcheries are employed as part of the restoration, specification of quality might include targets for postBrelease survival of propagated fish relative to survival of wild fish, the reproductive success of the returning adults, or 1ongBterm fitness or genetic structure of the hatchery and wild populations. The specification of quality for habitat restoration might include the re-expression of specific life history patterns in the target population. For example, in a river with highly regulated stream flow, natural patterns of flow and temperature might be reestablished through part of the year to restore historic migration timing of juvenile or adult salmon.

Patient-Template Analysis (Step 2)

Step 2 has been labelled Patient-Template Analysis (PTA). “Patient” describes the status of the life histories and habitat of the target population. “Template” describes the healthy habitat and life histories of the target population. A comparative analysis (diagnosis) of the patient and template identifies factors that may be limiting production and helps select the most effective and economical means of restoring natural production. The PTA assumes that natural productive capacity of a salmon population in freshwater, (e.g., total smolt output) is a function of habitat complexity and connectivity and life history diversity.

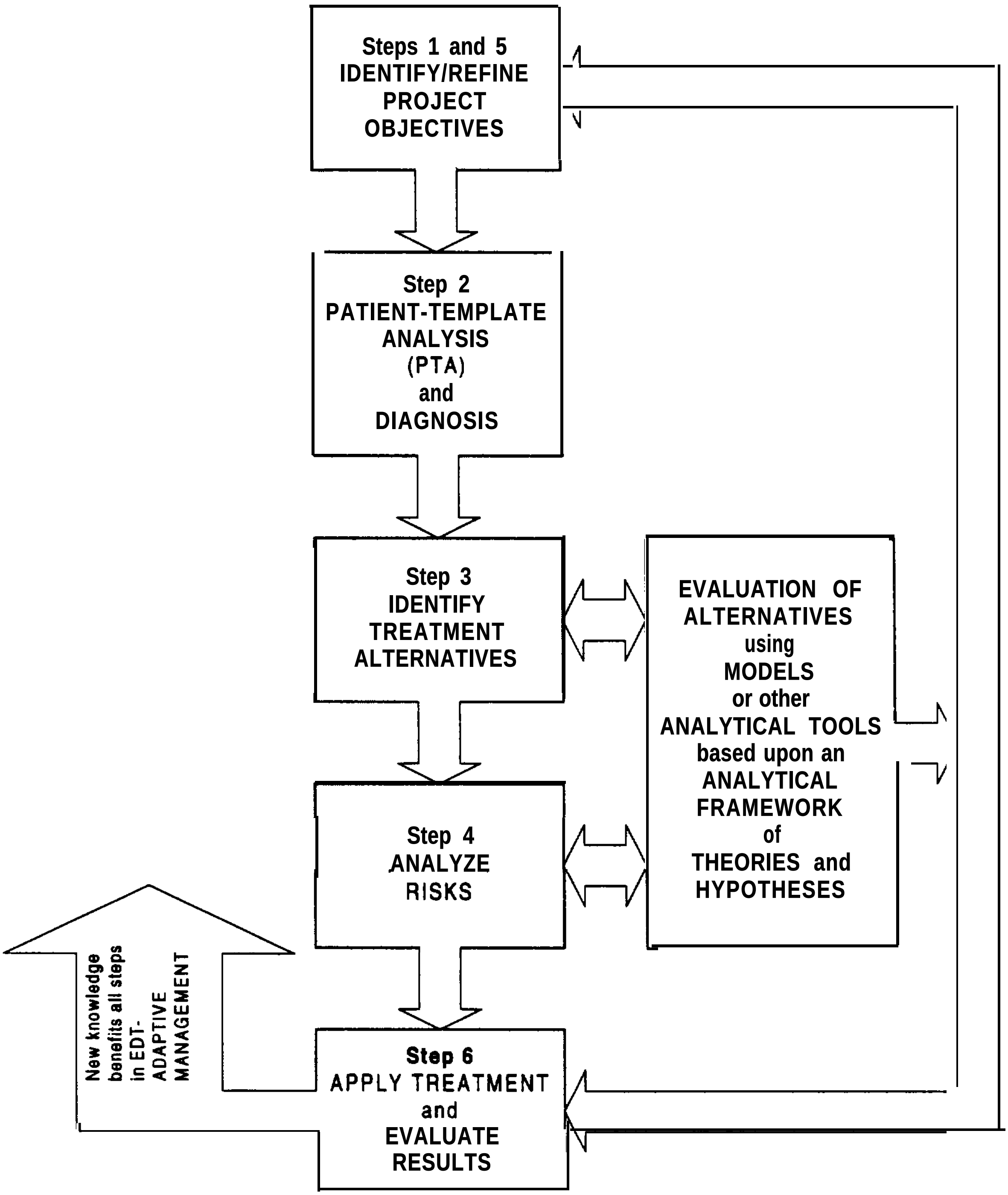

Figure 1. Steps in the ecosystem diagnosis and treatment(EDT) process.

The patient-template description combines three elements important to the life history-habitat relationship of the target stock:

- geography-the distribution and quality of salmon habitats in a watershed;
- time-the seasonal pattern of use and connectivity of those habitats; and
- biology-the biological function such as spawning, migration feeding, and escaping predators that takes place in those habitats.

Describing the template will usually require historical reconstruction inferred from the literature on the target stock or from the literature on stocks in similar systems. Developing the patient description might require field investigation as well as literature review.

One way to organize information needed to complete the PTA is through a series of matrices. RASP (1992) gives a detailed description of the matrices, and Watson (1992) used that approach to complete a PTA for spring chinook salmon in the Yakima River, Washington. PTA is also being used to develop a restoration plan for the spring chinook salmon in the Grande Ronde River, Oregon. The basic steps in the PTA, which are given in detail in RASP (1992) and Watson (1992), are:

1. The watershed is divided into environmentally distinct stream reaches. Criteria used to identify those reaches include thermal cycle, instream flow patterns, hydrographic problems (water diversions, headwater storage reserves), channel morphology, channel gradient and substrate character, riparian condition, predator densities, and connectivity of salmon habitats (Watson 1992).

The patient and template life history patterns are summarized based on the salmon's use of the individual stream reaches for spawning, summer rearing, winter rearing, and migration (Table 1).

3. Watson (1992) identified six life histories for the template spring chinook population in the Yakima River. The patient population exhibited only four life history patterns. Life histories may be differentiated by location of rearing and spawning, the timing of spawning and juvenile and adult migration, and size and age when juveniles enter saltwater. Table 1 identifies life histories by location only- the stream reach where life stages are completed. The timing of usage of those locations is not shown. A series of matrices - one for each life stage (spawning, spring/summer and winter rearing and juvenile, adult and smolt migrations) - are used to organize a qualitative description of life history, habitat condition, and production. Figure 2 illustrates the categories of information included in those matrices.

The diagnosis is the last step in the PTA. In the diagnosis, the template and patient are compared to identify what is preventing the realization of management objectives. The appropriate management activity to correct or circumvent the limitation is selected, and the life history-habitat relationships that restoration should attempt to rebuild or repair are described. Depending on the type and quality of the information available to construct the patient and template, the diagnosis may be qualitative or quantitative. Production bottlenecks can be described in two ways: a habitat or management

Table 1. A comparison of template and patient life histories for the Yakima River spring chinook salmon (adapted from Watson 1992). The template includes six life histories. In the patient, life histories IV and VI (shaded) are missing.

Life history pattern	Spawning location	Summer rearing location (fry to Parr)	Winter rearing location (presmolts)	Smolt age
I	Upper tributaries	Upper tributaries	Upper tributaries	1+
II	Upper tributaries	Upper mainstem	Upper mainstem	1+
III	Upper mainstem	Upper mainstem	Upper mainstem	1+
[illegible]	Lower tributaries	Lower mainstem	Lower tributaries	1+
V	All stream reaches above mainstem	All stream reaches above mainstem	Lower mainstem and associated “sloughs’	1+
VI	All stream reaches above lower mainstem	Lower mainstem	Not applicable	0+

problem that completely eliminates life histories, or a problem that suppresses the capacity of specific life histories but does not completely eliminate their expression.

Recommend Treatment (Step 3)

Treatments are the specific activities required to reduce or eliminate constraints on production identified in the PTA and to achieve the quality and quantity targets specified in the objective. The choice of treatment has to address the production bottlenecks and be consistent with the management objective. For example, the management objective is to increase natural production of chinook salmon in a tributary where low flows and excessive temperatures are barriers to the movement of juveniles from the tributary to the mainstem during summer months, e.g., the barrier totally suppresses the subyearling smolt life history pattern. Adult production is depressed, but habitat above the barrier is fully seeded by juveniles whose life history is compatible with the fragmented condition of the habitat. In this example, it would be inappropriate to recommend hatchery supplementation without correcting the low flow/thermal barrier.

Life history types	Spawning					
	Stream reach	Habitat quantity	Habitat quality	Timing	Incubation survival	Prespawning mortality

Life history types	Spawning (continued)				
	Species interactions	Age structure	Sex ratio	Fecundity	Availability of holding habitat and access to spawning areas

Life history types	Spring/summer rearing								
	Stream reach	Habitat quantity	Habitat quality	Timing	Density	Growth	Fry to parr survival	Species interactions	Habitat connectivit y

Life history types	Fall/winter rearing								
	Stream reach	Habitat quantity	Habitat quality	Timing	Density	Growth	Parr to smolt survival	Species interactions	Habitat connectivity

Figure 2. Suggested formats for the PTA matrices. Each row gives the top line of a matrix used to organize information on either the patient or template. The far left column (life history types) of each matrix identifies the intrapopulation life history patterns. The information called for in each remaining column is used to describe the life history pattern, characterize its habitat and estimate production. (From RASP 1992).

Life history types	Presmolt migration					
	Hydrograph	Timing	Migration survival	Species interaction	Access to rearing habitat	Physical **and** biological barriers to movement

Life History **Types**	Smolt migration					
	Hydrograph	Timing	Migration survival	Species interaction	Mainstem passage	Physical and biological barriers to movement

Life History **Types**	Adult migration						
	Hydrograph	Timing	Migration survival	Species interaction	Ocean distribution	Fisheries interception ocean/estuaries/rivers	Life History Summary

Fig. 2 cont'd.

In some cases the production constraint will consist of irreversible habitat degradation. Those bottlenecks might be circumvented by carefully designed artificial propagation programs. Reisenbichler and McIntyre (1986), Kapuscinski et al. (199 1), and Cuenco et al. (1993) provide guidance for appropriate ways to integrate natural and artificial propagation. Hall and Baker (1982), Reeves and Roelofs (1982), and Frissell and Nawa (1992) do the same for habitat restoration. The primary purpose of any treatment is to restore habitat complexity and connectivity and life history diversity to a natural, healthy state or as close to it as possible.

Risk Analysis (Step 4)

All uncertainties in restoration planning are resolved, temporarily at least, through assumptions that are either stated as part of the plan or implied in the recommended actions. Risk is a direct function of the cumulative effects of critical uncertainties associated with a recommended treatment. An uncertainty is critical if an incorrect choice or assumption can mean the failure to achieve objectives. Risk analysis is the evaluation of strengths and weaknesses of those assumptions. Planning assumptions for critical uncertainties must be clearly stated and documented with appropriate citations from the literature. Risk assessment can consist of a qualitative weighing of the assumptions or quantitative estimates of their impact on project success.

Incorporating risk into the decision process requires two steps: scientific inquiry and social evaluation. The level of risk can be determined through scientific evaluation of the uncertainties and assumptions. However, deciding how much risk to accept is a social evaluation. This is particularly true where artificial propagation is the proposed treatment because, in that case, the restoration method itself poses some risk (Hard et al. 1992). Social evaluation becomes important where restoration will incur large economic costs to the community.

Revise the Objective (Step 5)

At this point in the development of a restoration plan, the objective is revisited to determine if it is reasonable (and achievable) given the results of the PTA, recommended treatment, and risk analysis. The revised objective should describe what part of the template can be restored.

Design and Implement Monitoring and Evaluation (Step 6)

M&E has three objectives: (1) To determine if project objectives were achieved; (2) to monitor key ecological variables that will give early warning of a problem or surprise; and (3) to learn from the experience and improve future restoration projects. The purpose of No. 2 is to contain or manage risks. Information obtained through monitoring and evaluation should be used to revise the PTA and periodically generate a new iteration of the planning sequence.

DISCUSSION

A fundamental problem facing salmon managers is the need to incorporate an ecosystem perspective into restoration planning while focusing on the objective of increasing productivity of a specific component of the ecosystem C the salmon. Our approach to the problem is based on the premise that ecosystem health is the maintenance of complexity and self-organizing capacity

(Norton 1992), defined in terms of Pacific salmon. Complexity and selfBorganization are expressed as the intrapopulation life history diversity manifested within a complex habitat template. This concept is the central feature of the planning process described here and is embodied'in the PTA.

The approach focuses on the reconstruction of life history habitat relationships, the analysis of risks associated with alternative treatments, and monitoring and evaluation. Sustainability of rehabilitation is not merely a function of numbers but a re-establishment of important ecological relationships. In restoring salmon, the important ecological relationships are those between the habitat template and intrapopulation life histories. Sustainable restoration cannot be achieved through programs that focus entirely on numbers of fish. The specification of resource quality (e.g., life histories, age structure or distribution), must be included in restoration objectives. Where objectives include statements of resource quality, the risk of failing becomes important not only from the standpoint of harvest or escapement but of sustainability. Finally, without monitoring, learning cannot take place, and the machinery of adaptive management comes to a halt.

Too often in the history of Pacific salmon management, restoration programs were developed, implemented, and declared a success without the benefit of evaluation. This is especially true in the use of hatchery technology. The approach we describe recognizes that evaluation of what we do, learning from that evaluation and applying that information is a continuous process. We cannot avoid this process, if Pacific salmon are to have any hope for recovery.

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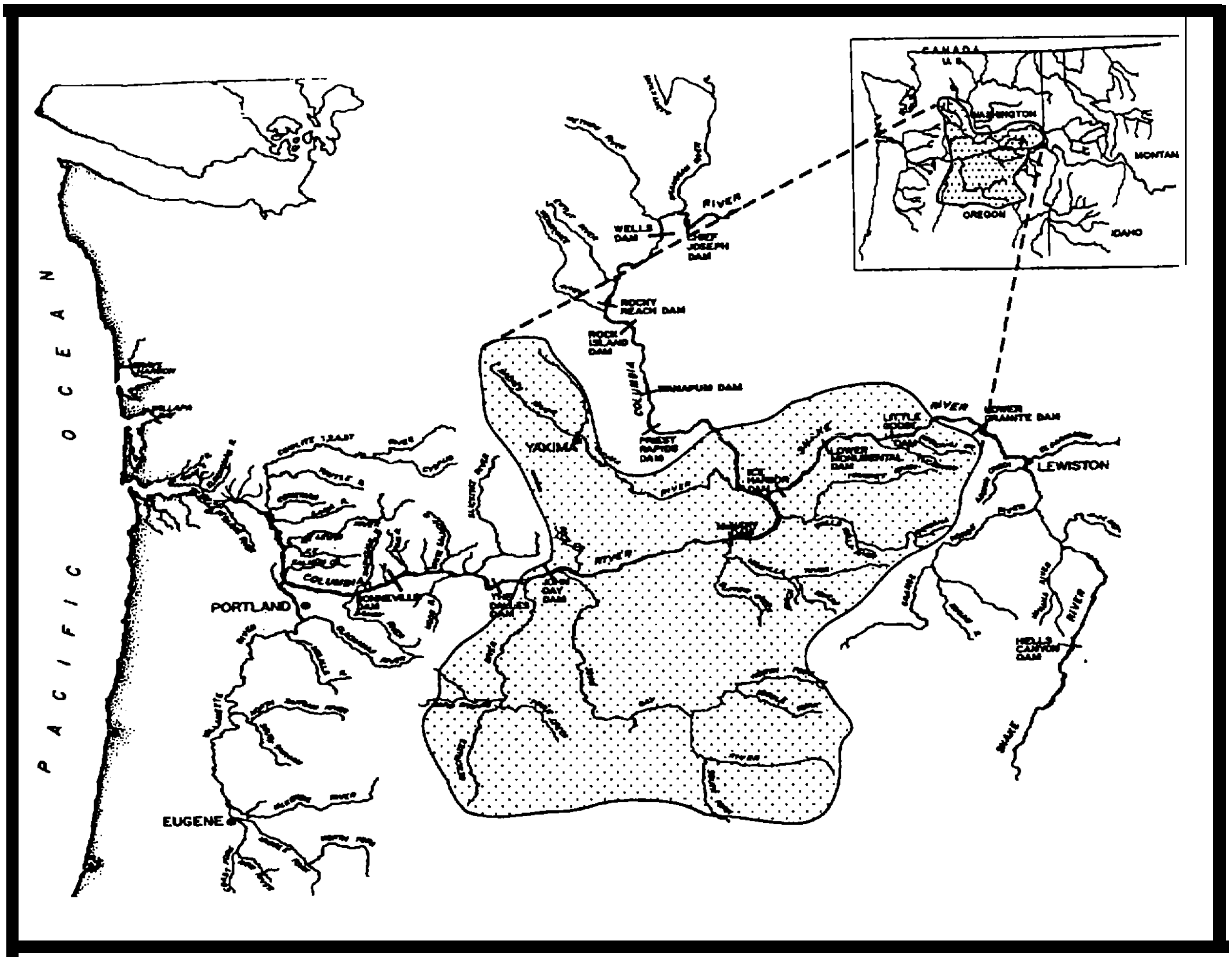

Analysis of Chinook Salmon in the Columbia River from an Ecosystem Perspective

January 1995

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EXECUTIVE SUMMARY

ANALYSIS OF CHINOOK SALMON IN THE COLUMBIA RIVER FROM AN ECOSYSTEM PERSPECTIVE

Ecosystem Diagnosis and Treatment (EDT) methodology was applied to the analysis of chinook salmon in the mid-Columbia subbasins which flow through the steppe and steppe-shrub vegetation zones. The EDT examines historical changes in life history diversity related to changes in habitat. The emphasis on life history, habitat and historical context is consistent with and ecosystem perspective.

This study is based on the working hypothesis that the decline in chinook salmon was at least in part due to a loss of biodiversity defined as the intrapopulation life history diversity. The mid Columbia subbasins included in the study are the Deschutes, John Day, Umatilla, Tucannon and Yakima.

Conceptual Framework

A major part of the study's conceptual framework is the conservative assumption that functional relationships between life history diversity and habitat diversity are adaptive although the genetic component may be small. This assumption implies that complex habitats with a high degree of connectivity permit the development and expression of diverse life histories. Further, the relationship between life history and habitat is an important determinant of an ecosystem's potential capacity and its performance in terms of salmon production.

Juvenile life history patterns in chinook salmon are classified into one of two general patterns: the ocean and stream types. Ocean type life history exhibits a short freshwater residence, usually migrating to sea within six months of emergence. Fish exhibiting the stream type life history migrate to sea in the spring of their second year. The ocean type life history pattern is dominate and will be exhibited where there is sufficient growth opportunity for the juveniles after emergence. The stream type life history is determined in part by photoperiod at the time of emergence and growth opportunity. Under healthy habitat conditions, a population of juvenile chinook will exhibit several variations of the stream or ocean life history types. These variations constitute an important part of the species biodiversity.

An important part of the conceptual framework is the assumption that life history is the salmon's solution to survival problems in its habitat and that multiple life histories are the salmon's solutions to survival problems in a fluctuating environment.

The conceptual framework also incorporates the effects of natural production cycles on the observed changes in the abundance of chinook salmon. Conventional wisdom attributes the decline of Pacific salmon in the Columbia River and elsewhere in the Northwest to over harvest, habitat destruction and the side effects of artificial propagation. These factors certainly contributed to the declines. However, cyclic changes in productivity also played a major part in the declines. The interactions between natural fluctuations in productivity and human activities over the past 100 years probably increased the depth of the troughs and depressed the height of the peaks in salmon production.

Findings

Intensification of commercial exploitation of chinook salmon in the Columbia River began in 1866. Since then, the harvest of chinook salmon can be divided into four phases: Initial development of the fishery (1866 to 1888), a period of sustained production with an average annual harvest of about 25 million pounds (1889 to 1922), resource decline with an average annual harvest of 15 million pounds (1923 to 1958), and maintenance at a depressed level of production of about 5 million pounds (1958 to the present).

The patterns in abundance of chinook salmon described strictly in numerical terms mask an important shift in resource quality that took place between 1890 and 1920. Spring and summer chinook were declining and to maintain production, harvest shifted from spring and summer chinook to fall chinook salmon. Since the 1960s, increases in the survival of hatchery reared fish created another shift in resource quality. Salmon of hatchery origin now make up about 80% of the total adult run into the Columbia River.

The decline of spring/summer chinook early in this century was attributed to over harvest and habitat destruction with over harvest generally receiving the greater emphasis. However, spring and summer chinook were particularly vulnerable to the kind of habitat degradation that took place in the last decades of the 19th and early decades of the 20th centuries. Grazing and timber harvest stripped away riparian vegetation and dried up wetlands. In the high desert subbasins, the loss of riparian cover has significant effects on the quality of salmon habitat including structural complexity and temperature. Another important source of habitat degradation was gravity irrigation systems which diverted water from rivers at higher elevations for distribution to farms at lower elevations. Because of their different spawning distributions, spring and summer chinook salmon were influenced most by irrigation diversions. Juvenile chinook salmon migrating downstream in late spring and summer, at a time of high demand for water, were diverted into unscreened irrigation ditches and left to die in large numbers in watered fields.

The clearing or over grazing of riparian vegetation and draining of wetlands adjacent to stream channels, channel straightening and water diversions for irrigation fragmented the habitat of salmon in the mid Columbia subbasins. The cumulative effects of development activities dewatered lower reaches of tributaries or elevated temperatures beyond the preference or tolerance of salmon. The combination of unscreened irrigation diversions and loss of riparian cover created thermal or physical barriers and caused a significant loss of productivity. The decline in productivity can be linked to the loss of the subyearling life history pattern.

CONCLUSIONS

A A conceptual framework based on the relationship between life history and habitat is a useful approach to the analysis of salmon problems over large areas of the Columbia Basin.

B The capacity and performance of the Columbia River ecosystem relative to Pacific salmon fluctuates naturally at millennial, decadal and annual intervals. Annual fluctuations are generally recognized and taken into account in the design of restoration programs. An understanding of millennial fluctuations helps establish historical context but has little impact on program design. Decadal fluctuations in productivity have important implications to the design, implementation, evaluation of the recovery program and the realization of program goals. Fluctuations in capacity at decadal intervals are not being adequately addressed.

C Chinook salmon in the Columbia Basin underwent important qualitative changes in the late 19th and early 20th centuries and again after 1960. The first change was the decline of the spring/summer run fish and the second change was the growth in the proportion of salmon of hatchery origin.

D Harvest may have been over emphasized as the cause of the decline of spring/summer chinook. Habitat destruction probably played a much greater role in the decline prior to 1920.

E Habitat fragmentation eliminated the dominant ocean type life history pattern and contributed to the decline of the spring/summer chinook salmon. Habitat fragmentation is characterized by the occurrence of lethal temperatures or extreme low flows through the summer months in the lower reaches of subbasins. The loss of the ocean type life history pattern constitutes a loss of biodiversity.

F The construction of mainstem dams increased habitat fragmentation by creating marginal migratory habitat in the mainstem Columbia River. Habitat was degraded through the conversion of a free flowing river to a series of reservoirs and through a change in normal flow patterns. The mainstem dams prevented any chance of recovery to the pre 1920 production levels.

G Restoration of spring/summer chinook salmon will require the restoration of habitats and habitat connectivity in both the mainstem and in the degraded subbasins.

IMPLICATIONS

A Management/restoration programs and the models or conceptual frameworks that those programs are derived from must account for natural fluctuations in habitat quality and salmon production. A failure to do so will at best reduce the possibility of successful restoration and possibly produce detrimental results.

B Monitoring of life history diversity in selected populations should be an important component of the regional monitoring and evaluation program.

C The use of EDT and its underlying conceptual framework gives important new insight into the decline of chinook salmon which has implications to the design of restoration programs.

D Habitat in portions of the mainstem and estuary of the Columbia has also been fragmented and degraded. Changes in flow patterns and development have altered the habitat quality and quantity in the mainstem and estuary further reducing life history diversity and productivity of estuarine dependent species such as chinook salmon. The application of EDT to other subregions in the basin should be considered.

E Habitat restoration in the upper reaches of subbasins might be targeted on life histories that did not make important contributions to the production of chinook salmon prior to habitat degradation. Improving the quality of remaining refugia habitats is not as important as restoration of connectivity -- improving the quality of habitat in the lower reaches of the subbasins.

F Management from an ecosystem perspective will require watershed-wide restoration programs that attempt to reconstruct historic habitats and life histories.

ANALYSIS OF CHINOOK SALMON IN THE COLUMBIA RIVER FROM AN ECOSYSTEM PERSPECTIVE

An Application of the Ecosystem Diagnosis and Treatment Methodology

"About 30 years ago there was much talk that geologists ought to observe and not to theorize; and I well remember someone saying that at this rate a man might as well go into a gravel pit and count the pebbles and describe the colors. How odd it is that anyone should not see that all observation must be for or against some view if it is to be of any service" **(Darwin and Seward 1903 cited in Mayr 1991 p. 9).**

INTRODUCTION

Purpose

The purpose of this report is to review the status of chinook salmon in several subbasins within the steppe and shrub-steppe vegetation zone of the Columbia Basin. The study looks at the decline of chinook salmon through an analysis of changes in life history diversity as related to changes in habitat quality. This approach is seldom used and it focuses on the historical changes in the environment in relation to changes in populations and their structure. The emphasis on life history and habitat and their historical context is consistent with an ecosystem perspective (Lichatowich et al. 1995).

Our basic premise is that the life history patterns of a population are a unique outcome of the habitat, particularly habitat complexity and connectivity and the population's genetic structure. Life history is the population's solution to survival problems in its habitat and multiple life histories within a population are the solutions to survival problems in a fluctuating environment. The interaction between life history and habitat is a major determinant of productivity and therefore provides a productive framework for the analysis of the historic decline of chinook salmon. Since it is not a conventional approach, it could yield unconventional insights into the causes of the decline and point to alternative restoration strategies.

The methodology employed in this study is based on the ecosystem diagnosis and treatment procedure (Lichatowich et al.1995), a broad approach to the development of salmon restoration plans which was derived from the Regional Assessment of Supplementation Project (RASP) (1992). To date, the approach used here has been applied to individual subbasins. However RASP (1992) stated that it could be applied to higher levels in the physical-biological hierarchy. The use of a consistent conceptual framework to evaluate declines and plan restoration is important to ensure that program measures are complimentary and consistent at the subbasin, subregional and regional or watershed levels. This project applies the approach to large ecological zone comprised of several subbasins. The results should be instructive to those attempting subregional and regional planning (e.g. NPPC 1994).

The study is based on the working hypothesis that declines in abundance are at least in part due to a loss of biodiversity defined as the intrapopulation life history diversity of chinook salmon. The mid-Columbia subbasins included in the study are the Deschutes, John Day, Umatilla, Tucannon and Yakima (Figure 1). The Walla Walla River was not included although it is in the same environmental zone which is characterized as steppe or shrub-steppe (Franklin and Dryness 1973) (Figure 2) within the Cascade rain shadow (Figure 3).[1] This particular study area was selected because rainshadow habitats are more vulnerable to the consequences of human development (Lichatowich 1993a). The analytical method employed in this study is a modified version of the Patient-Template Analysis (PTA) described by RASP (1992) and Lichatowich et al. (1995).

The study is comprised of five parts:

(1) Regional Environmental and Life History Patterns

This section presents a description of natural cycles in climate and productivity in the ocean and freshwater, a general description of chinook salmon life histories, and the factors influencing the expression of those life histories. This section establishes the conceptual framework for the study.

(2) Template Description

RASP (1992) defined the template as a description of healthy habitat and life histories in a subbasin. In this report the template describes the historic abundance of chinook salmon in the Columbia Basin, salmon habitat in the early decades of this century and historic life history patterns of chinook salmon in the study area. The template covers the period from predevelopment to 1940. Habitat degradation and stock

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[1] The definition of mid-Columbia used here is based on ecological and environmental criteria and may differ from other definitions of the mid-Columbia basin that are in use.

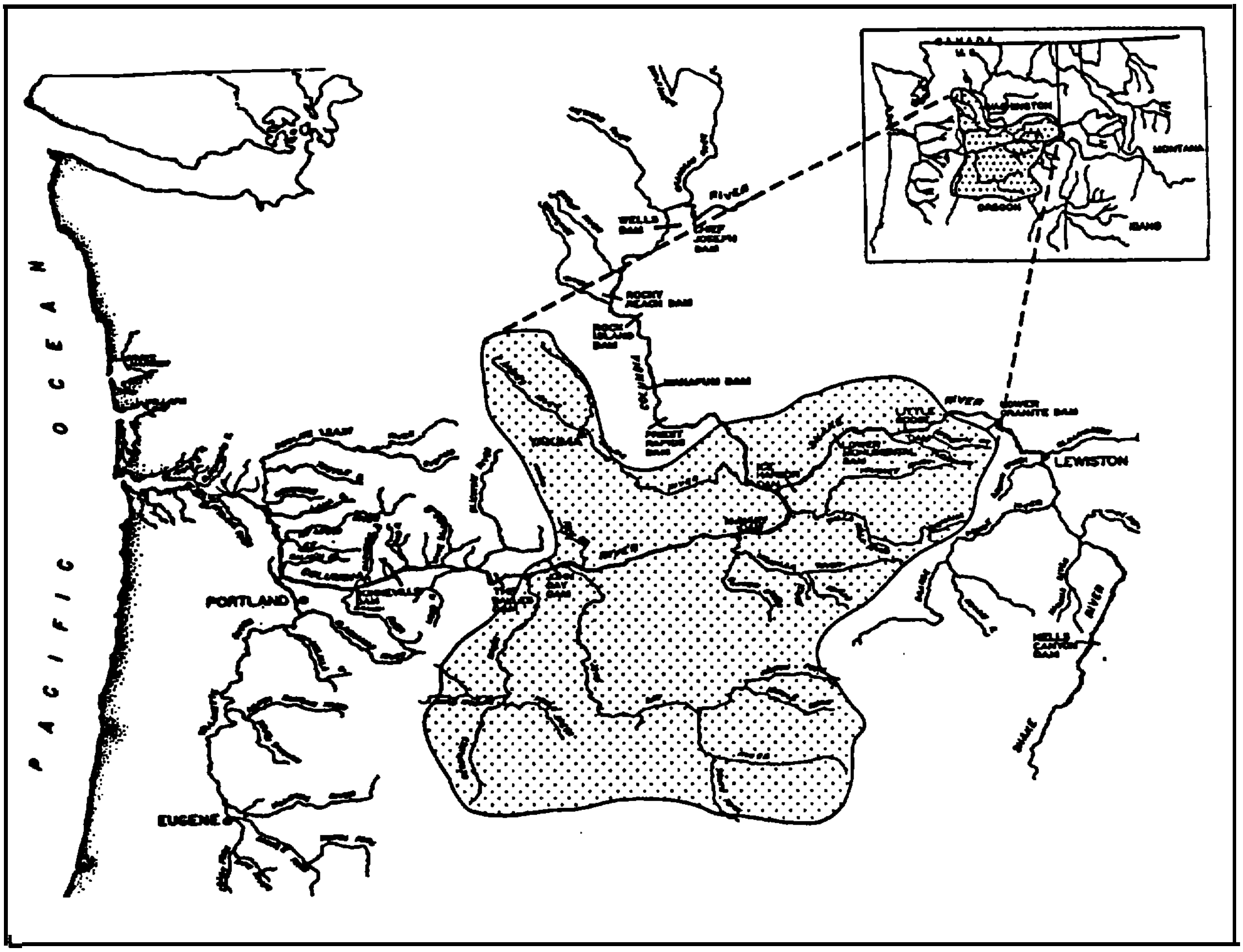


Figure 1. The Columbia River Basin. The area and streams included in this study are highlighted.

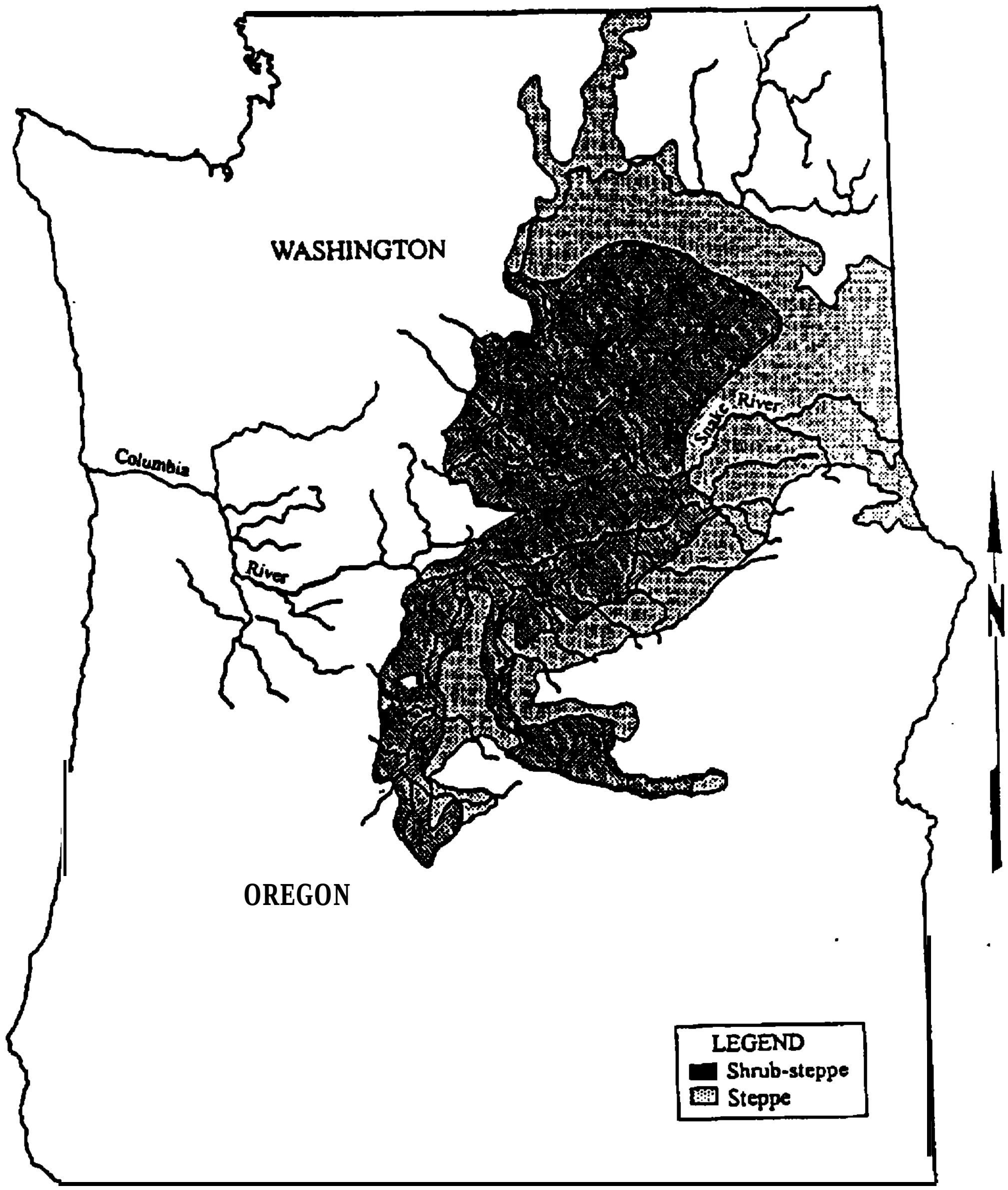


Figure 2. **The shrub--steppe and steppe vegetation zone in the mid-Columbia Basin. (From Franklin and Dryness, 1973, see Figure 1 for names of the subbasins.)**

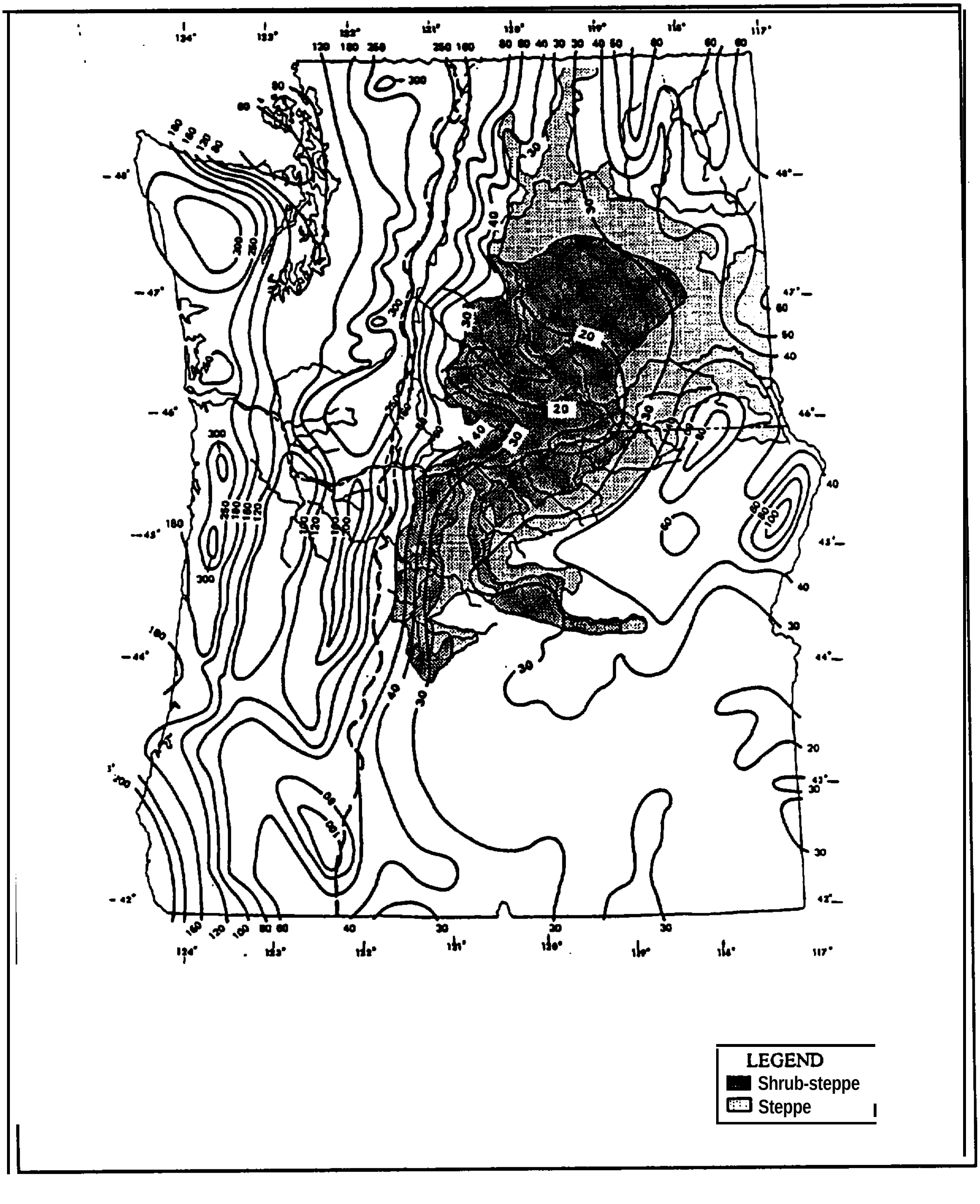


Figure 3. The Cascade rainshadow in relation to the study area illustrated by the isohyetal map of mean annual precipitation superimposed on the steppe and shrub-steppe vegetation zone. Precipitation in cm. (From Franklin and Dryness, 1973)

depletion took place prior to 1940. However, the decade of the 1940s was a major turning point for the river's salmon populations because during and after that decade! the river underwent major transformation as the basin's hydroelectric potential was developed. A direct loss of 31% of the historic salmon habitat was attributed to water development projects (NPPC 1986).

(3) Patient Description

The patient describes the current (post 1940) abundance of chinook salmon in the basin and study area. Current life histories of chinook salmon and current status of salmon habitats in the subbasins within the study area are also described.

(4) Diagnosis

The diagnosis compares the patient and template to identify constraints on salmon production.

(5) Discussion

The discussion evaluates the working hypothesis and its critical uncertainties.

Patient-Template Analysis - Basic Concepts

Since PTA is a relatively new approach to restoration planning, a brief review of its important concepts is appropriate. PTA was originally developed to determine when supplementation is an appropriate restoration strategy and to help managers plan for the most effective use of supplementation in salmon restoration (RASP 1992). However, the basic approach has utility beyond supplementation including the development of habitat rehabilitation plans (Lichatowich et al. 1995). PTA is currently being applied to salmon restoration planning in the Yakima, Lemhi and Grande Ronde rivers in the states of Washington, Idaho and Oregon, respectively.

The template describes healthy habitat and life history relationships and the patient describes existing status of the habitat and life history of the population to be restored. The template is a pattern against which the present condition (patient) and the proposed future condition (restoration objective) are compared to identify production constraints and reasonable expectations for increased performance through natural or artificial production.

The template description should not be confused with the restoration objective. The template describes the historical performance of target populations in a watershed. The objective describes that part of the template that management activities will attempt to restore. In a few cases the template and objective will be the same, in very few cases the objective might exceed the template, and in most cases, the objective will represent only a part of the original performance.

A principal purpose of PTA is to assist in the identification of constraints on salmon production. Once production bottlenecks are identified appropriate remedial actions can be selected. PTA is based on two critical assumptions: 1) Population infrastructure observed or measured as life history diversity is an important determinant of a population's performance; and 2) the physical and biological elements comprising a watershed or ecosystem are organized in a hierarchical system which has to be considered when setting the scale of restoration planning and implementation.

Population Infrastructure

To achieve sustainable recovery of degraded salmon populations, an important goal of restoration programs should be to restore functional relationships that determine a system's potential productive capacity. Management programs (e.g., harvest regulations, hatchery operations and habitat protection) must enhance the performance of target populations of salmon within the watershed or subbasin. Important functional relationships include life history variants that adapt a population to its habitat.

An important determinant of a system's productive capacity is the degree to which its component salmon populations are adapted to the range of environmental conditions encountered in the subbasin, mainstem, estuary and nearshore ocean. In the Northwest, salmon populations have adapted to an extremely wide range of habitat conditions — streams flowing through deserts and rain forests; tidal streams and high elevation headwaters. The adaptive relationship between a salmon population and its habitats can be diminished or destroyed in three ways:

(1) Human activities that shift environmental conditions (e.g., cover, temperature, hydrograph, and substrate composition and stability) so there is little overlap with the range of conditions to which the population has adapted. Natural catastrophic events can also change habitat faster than the population can adapt.

(2) The habitat may not change but the stock's genetic structure and therefore its adaptiveness might be altered by management practices such as selective fisheries or hatchery practices.

(3) A combination of 1 and 2 above.

All salmon habitats naturally undergo changes in quality due to natural processes. Adaptation implies that a population with a history of exposure to natural fluctuations in habitat quality has retained in its genetic structure the potential to express the traits needed to survive and remain productive within the range of the historic natural change. Life history studies are one way to observe the expression of those traits. Life history diversity is a mechanism populations use to “spread the risk” of mortality in fluctuating environments (Den Boer 1968).

The genetic infrastructure of a population is the product of selection, straying, mate selection and random process. Variability in the infrastructure may be partitioned spatially and temporally among population segments (Gharrett and Smoker 1993a) and observed as the timing and distribution of life history events such as adult migration and spawning and juvenile rearing and migration.

Life history traits such as migration timing may be the expression of quantitative genetic variation, a passive response to the environment or a combination of both genetics and environment. It is not easy to confirm the genetic basis of life history traits (Gharrett and Smoker 1993b) or that the traits are adaptive (Taylor 1991). Consequently geneticists have often ignored the study of quantitative traits (life histories) and focused on selectively neutral qualitative traits which can be examined through biochemical studies of allozyme variation (Gharrett and Smoker 1993b). Some parallel studies of allozyme variation and life histories have been completed. For example, the timing of juvenile and adult migration has been related to genetic variation (e.g., Gharrett and Smoker 1993a and Carl and Healey 1984). The study of life history traits and their genetic basis. should receive more emphasis.

A cornerstone of the PTA is the conservative assumption that functional relationships between life history and habitat diversity are adaptive and have a genetic basis, although the genetic component may be small, i.e., some life history traits may have a strong environmental component. This assumption implies that complex habitats with a high degree of connectivity permit the development and expression of diverse life histories. Further, the relationship between life history and habitat is an important determinant of a system’s potential capacity and its performance in terms of salmon production.

Hierarchical Organization

Biologists often view the biological systems that support and produce important fish species such as Pacific salmon as having different levels of organization (Warren 1971). Two forms of biotic hierarchical organization are: 1) Physiological system, individual organism, population and community; and 2) the trophic hierarchy of producers, consumers and decomposers. The physical system can also be divided into a hierarchical structure: Pool/riffle, reach, tributary and watershed. Although all levels of biological organization interpenetrate, managers often concentrate their efforts and define their programs within the limits of specific spatial/temporal scales and particular levels in a hierarchy (Warren 1971, O'Neill et al. 1986).

RASP (1992) suggested that PTA can be applied to restoration planning at various levels in the physical-biological hierarchy comprising the Columbia River Ecosystem. However, to date, PTA has been applied only at the individual subbasin/population level of organization. This study is the first attempt to extend the application of PTA to an ecological region comprised of several subbasins and populations. A planning process that can be applied at all levels in a system's hierarchical organization promotes internal consistency among program elements. Internal consistency is a prerequisite to the design of an efficient monitoring and evaluation program.

Selecting the appropriate level in the hierarchy to focus restoration planning is basically a problem of setting ecosystem boundaries. The boundaries will vary depending on the problem being addressed. For example, the Council's Fish and Wildlife Program (Northwest Power Planning Council (NPPC) 1987 and 1992) should define a boundary equivalent to the Columbia River watershed. Monitoring and evaluation might be designed to track progress toward program goals on a regional level where as the design of individual restoration projects focuses on subbasins or tributaries within subbasins. The spatial/temporal scale of the perturbation causing the problem that restoration is trying to correct should determine the spatial/temporal boundaries for planning purposes. A region-wide decline in production due to climate fluctuation cannot be adequately addressed through site specific supplementation projects. Managers must avoid the trap of selecting scales of convenience rather than scales at which the ecosystem is responding (O'Neill et al. 1986).

Often, in response to political pressure or the pressure to resolve immediate crises, management agencies compress the spatial/temporal scales of problem definition, management, and restoration planning. This year's harvest and allocation debates are the center of attention; habitat that is being destroyed today needs protection; hatchery managers want to release this year's production in healthy condition; and research/restoration programs become lists of projects to meet immediate needs instead of integrated programs based on a conceptual framework of appropriate spatial/temporal scale. Although the immediate problems are often the result of factors operating on broader time and space scales, it is often more convenient to treat them as simple isolated events. By specifically calling attention to history and ecosystem boundaries, PTA attempts to avoid the myopia that can creep into restoration planning.

REGIONAL CLIMATE AND LIFE HISTORY PATTERNS

The evaluation of habitat quality is almost always limited in temporal and physical scale. Smith (19931, Sedell and Luchessa (1981) and McIntosh (1992) are exceptions, i.e., those studies present analyses of habitat quality over large spatial/temporal scales. Selecting the appropriate scale is an important decision in any study of ecological systems (O'Neill et al. 1986). This is particularly true where system capacity and the performance of important components (e.g. salmon) are influenced by decadal or longer climate fluctuations. Beamish and Bouillon (1993), Lawson (1993) and Thompson (1927) describe the implications to management and problems of interpretation posed by the existence of long-term productivity cycles. This review of salmon abundance, life history and habitat in the Cascade rainshadow would be incomplete and possibly misleading without consideration of the long-term productivity cycles that influence performance at all levels in the hierarchical organization of the mid-Columbia River ecosystem.

Productivity Cycles

Climate, habitat and salmon production in the mid-Columbia Basin have fluctuated on a millennial scale (Figure 4). Using paleoscientific methods, more specifically, . the species composition and growth of freshwater mussels found in shell middens in archaeological sites in the Columbia Basin, Chatters et al. (*in* press) concluded:

- Flows in the Columbia River were 30 to 40 percent below current levels >6,000 years before the present. During a cool and wet period 2,300 to 3,400 years before the present, flows were 30 percent above current levels.
- During the period from 7,900 to 5,500 years ago, the annual summer freshet ended by late June. Later, (3,400 to 2,300 years ago) the freshet extended into August.
- Prior to 3,900 years before the present water temperature was above 10°C for 200 days a year. Temperatures have dropped to less than 130 days above 10°C at the current time.
- Sedimentation was much higher 6,000 years ago.

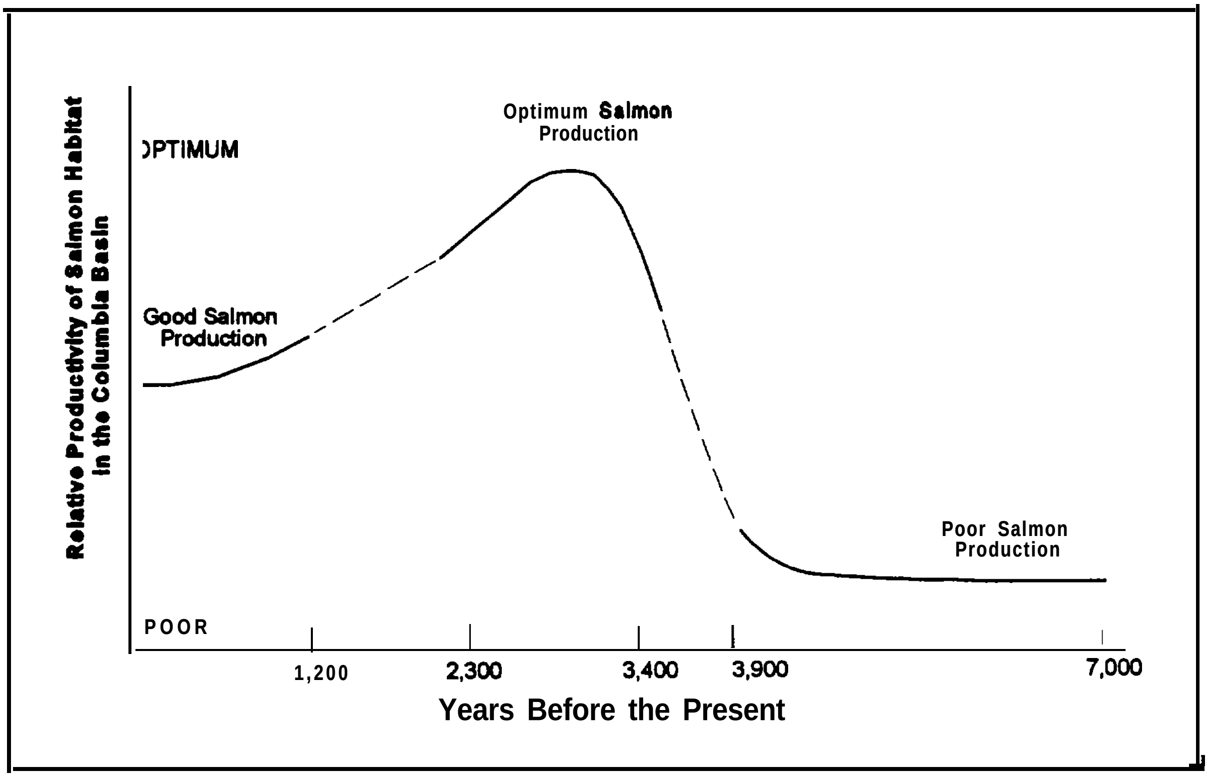


Figure 4. Relative productivity of Pacific salmon in the Columbia Basin during prehistoric times. Based on Chatters et al. (in *press).* Dashed lines indicate periods where data are lacking.

These patterns generally correspond to the occurrence of salmon in archaeo faunas at sites of prehistoric human occupation in the Columbia River. Archaeo fauna was comprised of a higher percentage of salmon remains during periods identified as favorable to salmon production and salmon remains comprised a smaller percentage of Archaeo fauna during periods of unfavorable conditions (Chatters et al. *in* press) (Figure 4).

The evidence presented by Chatters et al. *(in* press) strongly suggests that on a millennial scale the evolution of the Columbia River ecosystem has followed a nonlinear trajectory. This environmental history suggests a connection with current problems. Historically, a natural change in the duration of the summer freshet probably influenced the timing of juvenile salmon migrations in much the same way that a change in the hydrograph due to large storage reservoirs has altered salmon migration and survival today (e.g., NPPC 1994).

Three recent papers present evidence for decadal scale fluctuations in climate and fisheries productivity in the Northeast Pacific: 1) Primary and secondary production and biomasses of pelagic fishes in the California Current fluctuate on a 40 to 60 year oscillation (Ware and Thomson 1991); 2) the abundance of salmon in the North Pacific corresponds to the long-term fluctuation in the Aleutian low pressure system (Beamish and Bouillon 1993); and 3) survival of coho salmon in the Oregon Production Index (OPI) is determined by the intensity of coastal upwelling (Nickelson 1986) which at least partially explains a 50 year cycle in coho salmon *(Oncorhynchus kisutch)* production (Lichatowich *in press).*

Ware and Thomson (1991), Beamish and Bouillon (1993) and Nickelson et al. (1986) analyzed data collected after 1900 which was after the commercial salmon fisheries were well developed and severe habitat alteration had already occurred. However, an index of the standing stocks of pelagic fishes in the California Current is available for a 200 year period extending back prior to the commercial salmon fisheries. Historic standing stocks of pelagic fishes (hake, *Merluccius productus;* sardine, *Sardinops sagax*; and anchovy, *Engraulis mordax*) were reconstructed from scales contained in core samples taken from anaerobic sediments (Soutar and Isaacs 1974 and Smith 1978) (Figure 5). Those data show two features relevant to this study: 1) A 200 year peak in standing stocks near the turn of the century was followed by a 200 year low in standing stocks in the 1930s and 1940s, and 2) the magnitude of the change between the peak standing stocks around 1900 and the lows in the 1940s was the largest in the 200 year data set. The Oregon harvest of coho salmon parallels the trend in marine standing stocks (Figure 5).

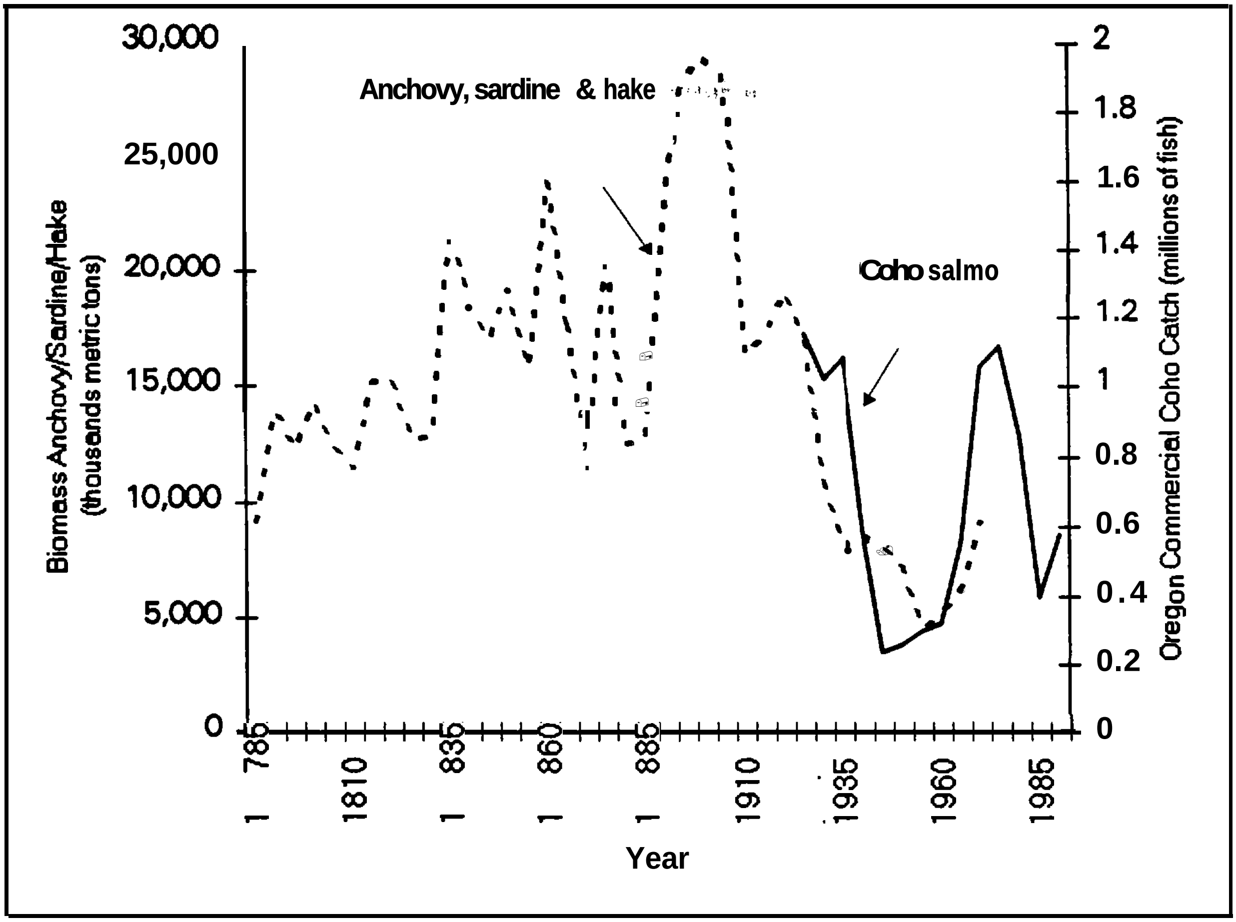


Figure 5. Total biomass of anchovy, sardine and hake in the California Current in thousands of metric tons. Standing stocks inferred from contemporary stock size and scale deposition rates in 18th and 19th centuries. (From Smith 1978) Commercial catch of coho salmon in millions of fish. Annual coho salmon harvest averaged by 5 year intervals. (Taken from Lichatowich 1993b)

Decadal fluctuations in the catch of coho salmon and standing stocks of pelagic fishes in the California Current correspond to indices of climate in the Columbia River Basin (Figure 6). Historic climate inferred from spacing of growth rings on trees is an index of the quality of the salmon's freshwater habitat. A period of cool-wet weather especially in the Snake River around 1900 was followed by a severe hot-dry period which lasted through the end of the data record in the mid-1940s. A different study which used a larger sample of trees covering a greater

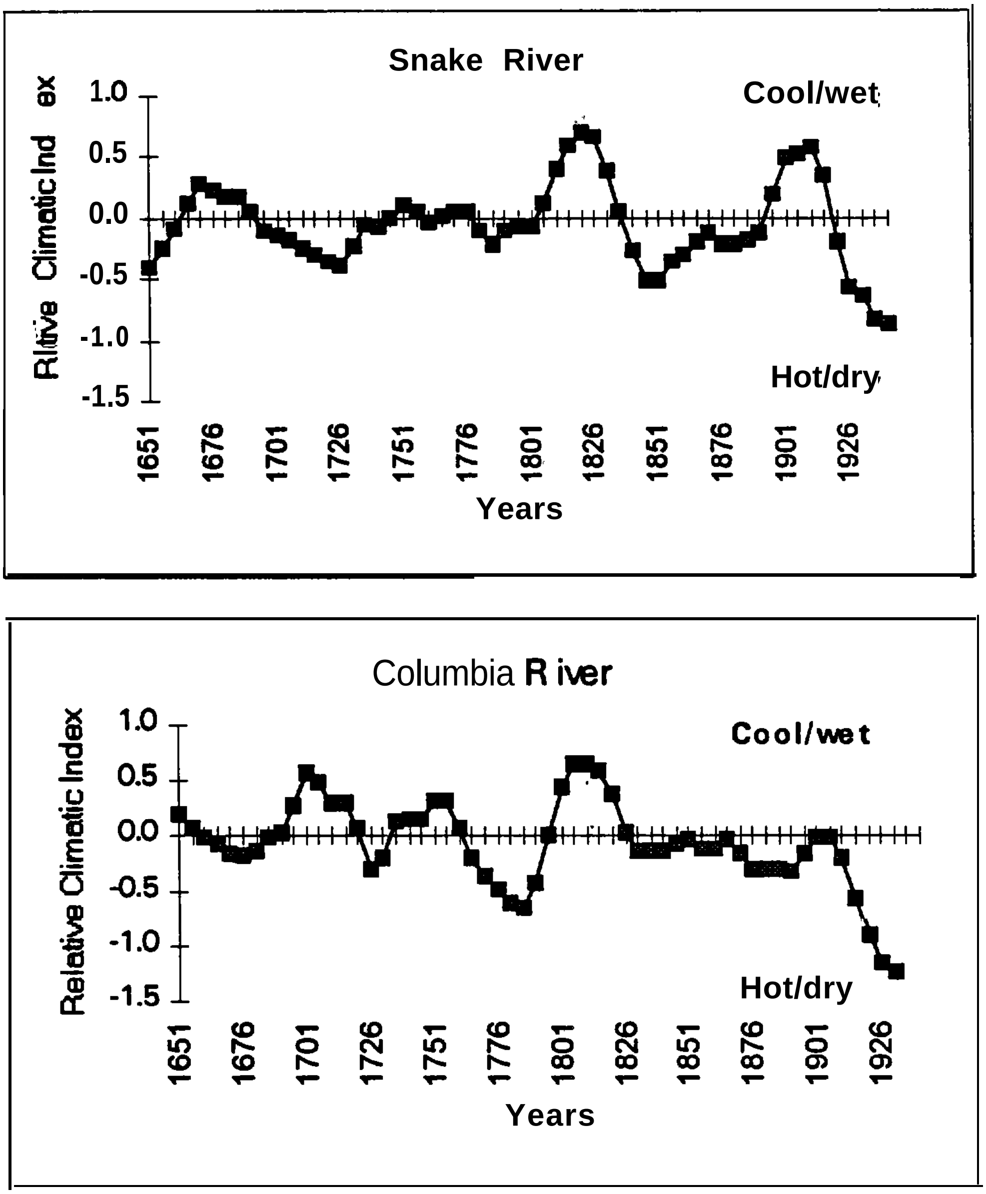


Figure 6. Fluctuation in an index of climate inferred from growth rings of trees in the Columbia Basin. Shown are five year moving averages of relative departures from a 270 year mean. Positive departures indicate cool/wet climate and negative departures indicate hot/dry climate. (From Fritts 1965)

geographical area in the Columbia basin also showed the higher level of precipitation around 1900 followed by declines through 1920s, 1930s and 1940s (Graumlich 1981). Reconstruction of historic temperatures in the Andrews Forest, Oregon (Figure 7) shows periods of cool temperatures in 1892-1920 and 1947-1976. Warm temperatures prevailed in 1921-1946 and since 1977 (Figure 7).

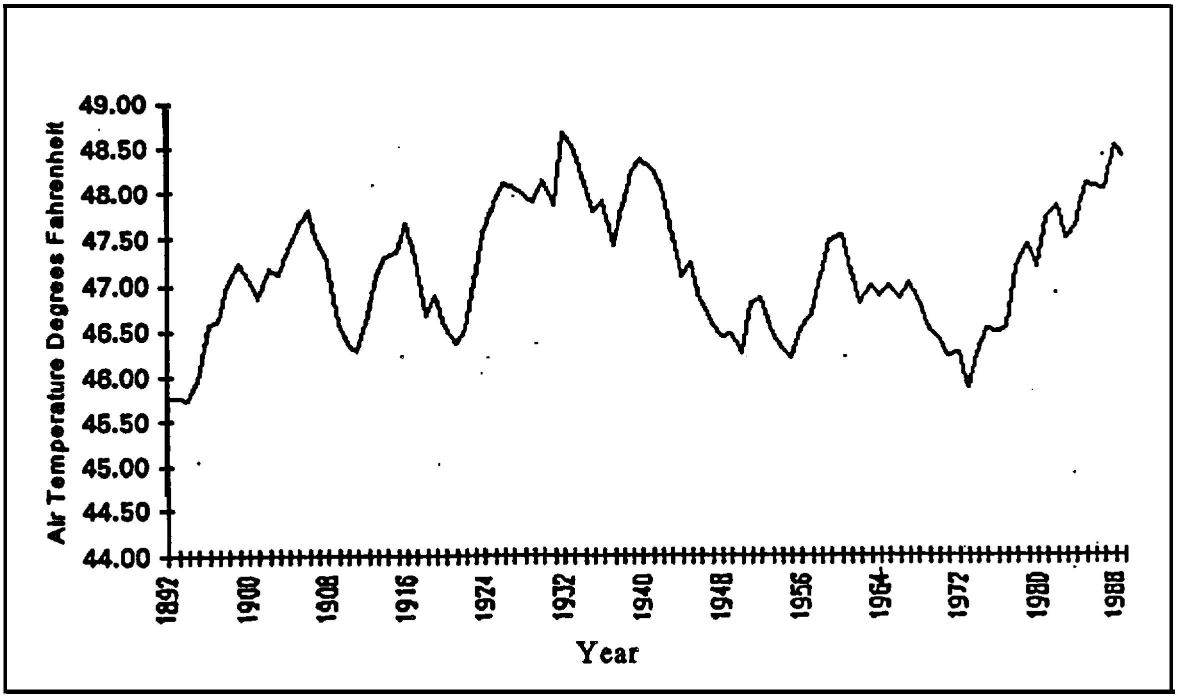


Figure 7. Reconstructed annual mean temperature in Andrews Forest in Oregon's central Cascades. (From Greenland 1993)

Large scale climate change probably influenced salmon production through changes in quality of both freshwater and marine environments during 1900-1940. Commercial landings of chinook, coho, sockeye *(Oncorhynchus nerka)* and chum *(Oncorhynchus keta)* salmon in the Columbia River and chinook and coho salmon in Oregon coastal streams were in decline between 1920-1940 (Figures 8-9). In addition, the catch of chinook and coho salmon in Puget Sound showed significant declines between 1896-1934 (Bledsoe et al. 1989) (Figure 10). The preceding suggest that salmon were in general decline in the Northwest in the period 1920-1940 and'the decline was in part due to a long-term fluctuation in climate. The current decline of salmon to historic low levels appears to correspond to a shift in climate that started about 15 years ago (Figure 7). The greater depth of the current production trough reflects increased habitat degradation.

The salmon fishery developed rapidly between 1880-1900 during a period of high productivity in the marine environment and favorable climate in freshwater areas. Those conditions probably established harvest expectations that could not be maintained in the long term (Lichatowich in *press).*

Conventional wisdom attributes the decline of Pacific salmon in the Columbia River and elsewhere in the Northwest to overharvest, habitat destruction and the side effects of artificial propagation. They were certainly major factors in the decline. However, if managers are to develop an understanding of the mechanisms of the decline and develop a sound approach to restoration, they have to incorporate into their analysis and planning the influence of cyclic changes in productivity. The extended ecosystem (fresh water, estuarine and marine habitats) of salmon from the Columbia Basin fluctuates in productivity at annual, decadal, and millennial scales. The interactions between natural fluctuations in productivity and human activities over the past 100 years probably increased the depth of the troughs and depressed the height of the peaks in salmon production (Figure 11).

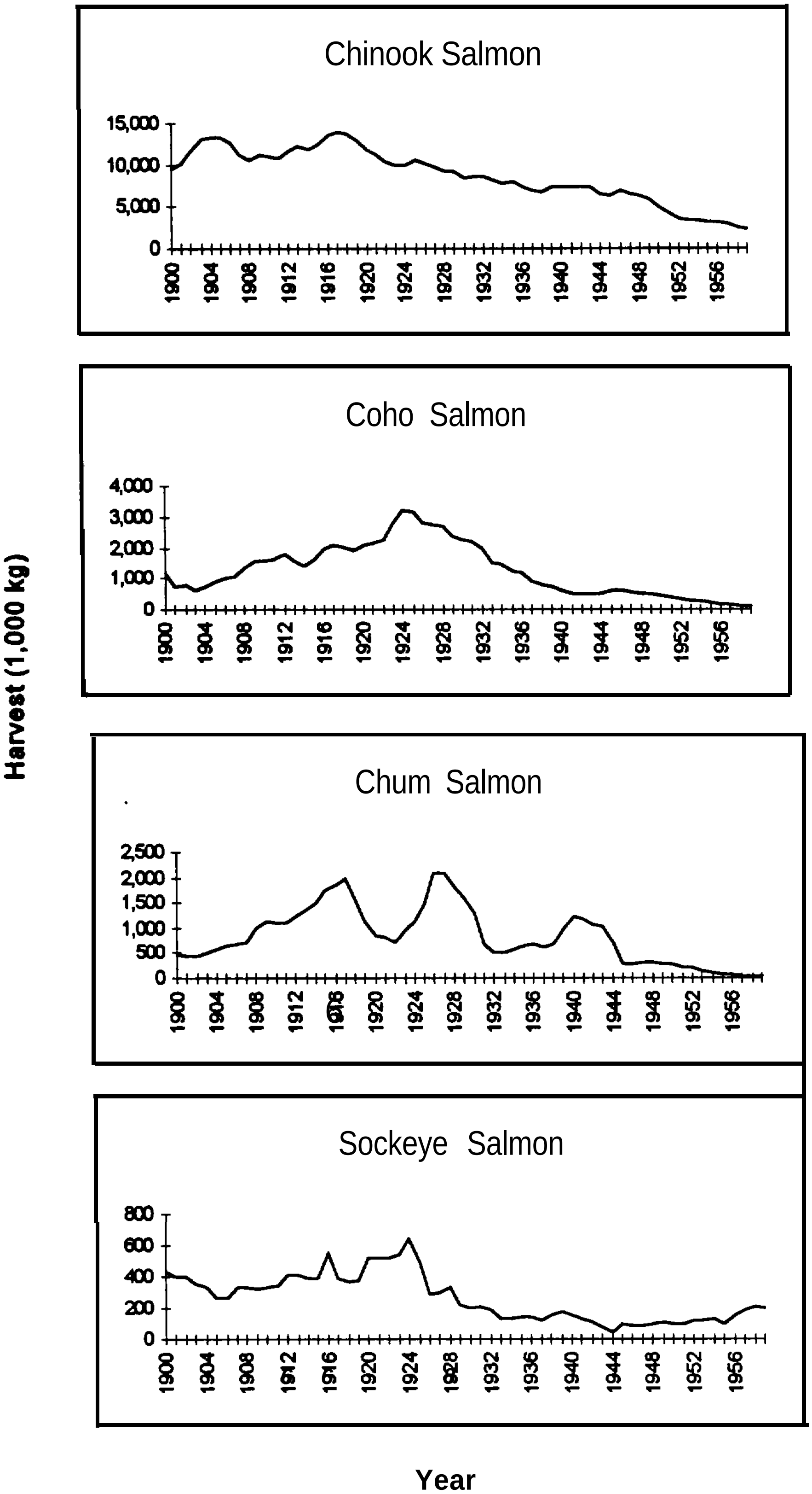


Figure 8. Five year moving average of commercial salmon harvest (thousands of pounds) in the Columbia River. (From-Beiningen 1976)

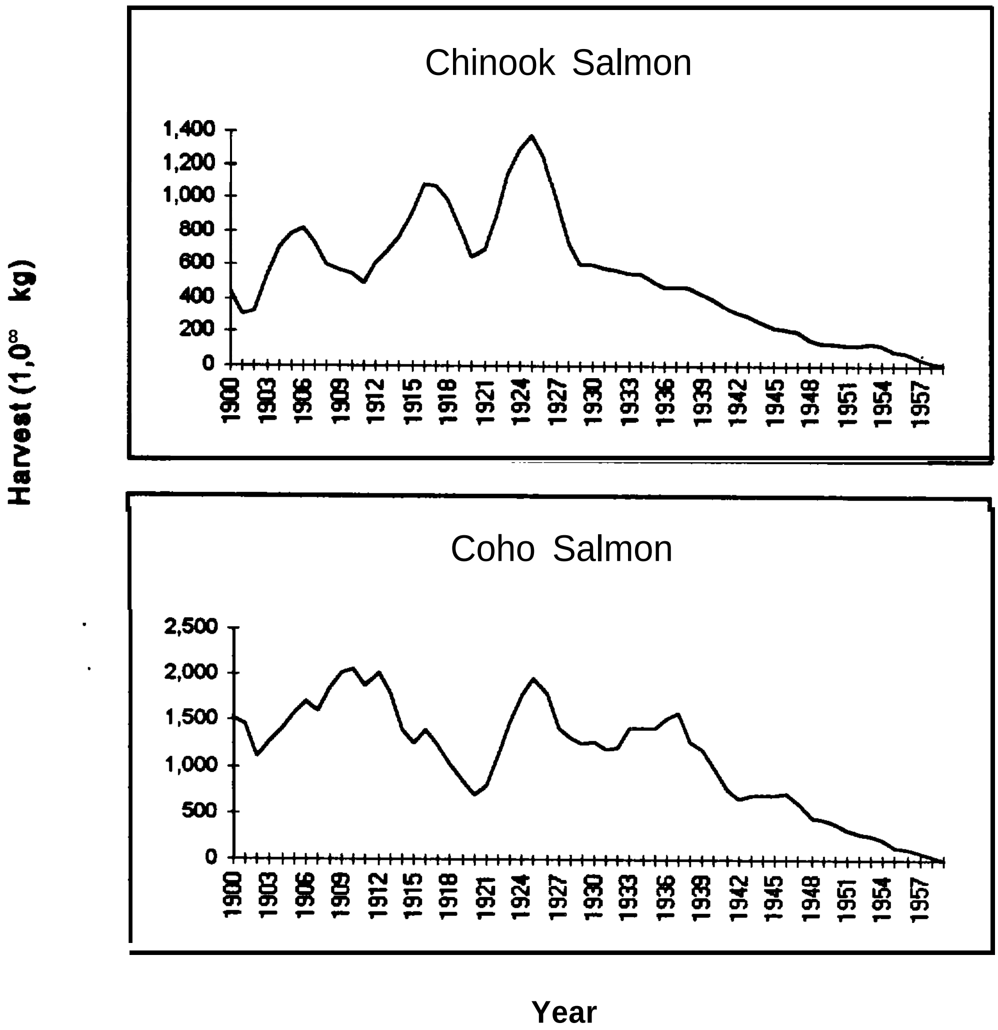


Figure 9. **Five year moving average of the commercial chinook and coho salmon harvest in Oregon coastal rivers. (From Mullen 1981 and R. Mullen, unpublished data, Oregon Department of Fish and Wildlife)**

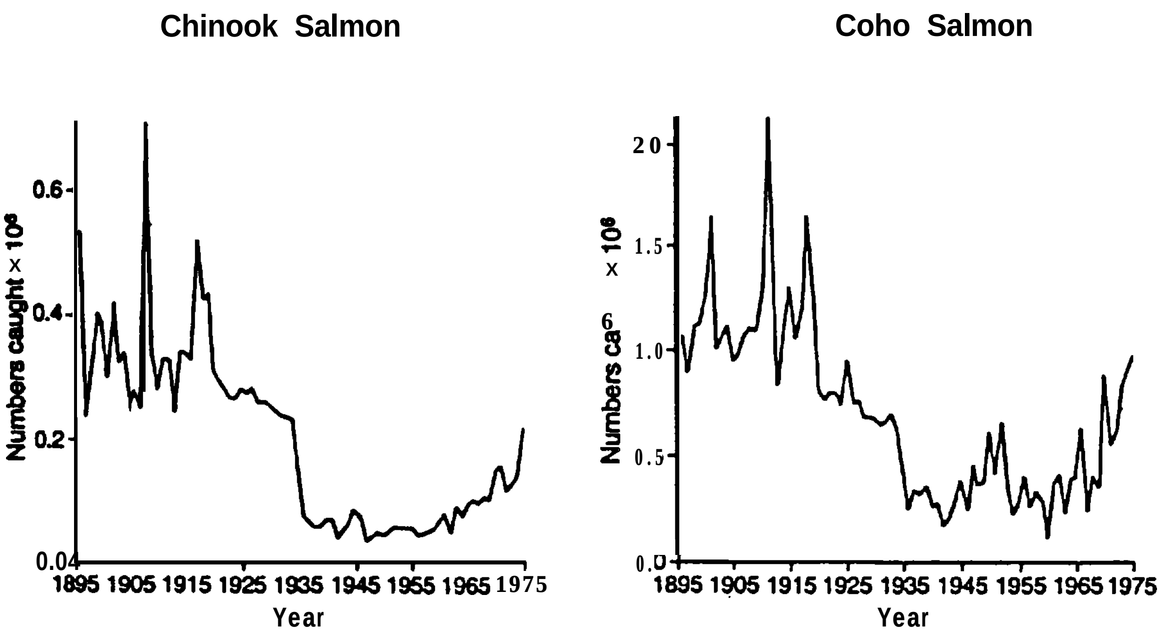


Figure 10. Catch of non-hatchery Puget Sound coho and chinook salmon. (From Bledsoe et al. 1989)

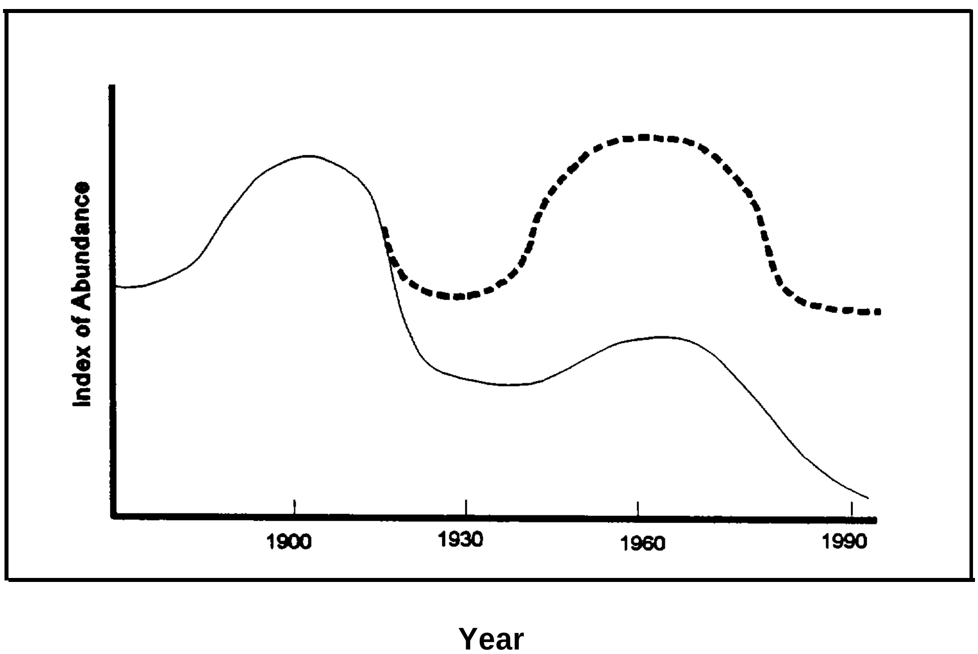


Figure 11. Hypothetical representation of salmon abundance in the Northwest over the last 150 years. The solid line illustrates the response of salmon to natural fluctuations in climate and productivity. The dashed line represents the probable production without intensive harvest, habitat destruction, and the negative effects of hatcheries.

LIFE HISTORY

> ***"Life histories lie at the heart of biology, no other field brings you closer to the underlying simplicities that unite and explain the diversity of living things and the complexity of their life cycles. . . . Its explanatory power, barely tapped, could reach as far as communities"***
> **(Stearns 1992, p. 9)**

Life histories are comprised of demographic traits such as age at maturity, mortality schedules, size and growth (Stearns 1992). In salmon, the interaction between demographic traits and migration within the salmon's extended ecosystem creates additional life history traits such as the age and size that juveniles migrate to sea, growth and maturity during ocean migrations and age and timing of spawning migrations. Life history traits are directly related to reproduction and survival and, therefore, are an important link between phenotype and genotype. They are a link between the fitness imparted by life history variants and the genetic consequence of differences in fitness among those variants (Stearns 1992).

Since habitats are templates for the organization of life history traits (Southwood 1977) each population's life histories must be considered in the context of its habitat. The expression of life history diversity in a complex and connected habitat structure is an important component of the adaptive capacity of the population or stock especially in fluctuating environments (Gharrett and Smoker 1993b). Diversity in the face of environmental uncertainty is the means by which the population spreads the risk of mortality and dissipates the probability of a catastrophic extinction (Den Boer 1968). The life history-habitat relationship is not static, it is a co-evolutionary process. Suitable habitats are colonized by appropriate life histories, and as habitats change, those life histories lose their fitness and cease to exist or are replaced by other life histories (Weavers 1993). Intrapopulation life history diversity distributes animals among favorable habitat patches similar to the way individual populations are distributed among habitat patches within a metapopulation structure (Hanski and Gilpin 1991).

The development and maintenance of life history diversity is a function of the habitat, genetic structure of the population and external selection factors. In Pacific salmon, habitat change, a loss or shift in life histories, and a change in fitness can result from natural or human causes. Long-term fluctuation in climate, and catastrophic events such as land slides, volcanism and fire are natural events that alter habitat availability and quality and the fitness of life history variants. Selective harvest, hatchery operations (e.g., broodstock selection, straying,

domestication), dams that block migration or kill migrants, water withdrawals for irrigation, or other consumptive water use and land use practices that destroy the riparian zone of streams also alter the fitness of life history variants.

Life history diversity is a readily observable feature of salmon populations which is related to fitness and productivity of the stock. Life history then, should be an important focus of management and restoration programs (Weavers 1993). However, life history has generally been treated as a generic or invariant trait of the species or race. Recent studies of intrapopulation life history diversity (Lestelle et al. 1993; Gharrett and Smoker 1993a; Carl and Healey 1984; Reimers 1973; Schluchter and Lichatowich 1977) are exceptions. Where intrapopulation life history diversity has been looked for and evaluated it has generally been found to have management application.

Chinook Salmon Life Histories

Healey (1991) structured the life histories of chinook salmon around two patterns of freshwater residence during the juvenile life stage. The two patterns were first described by Gilbert (1912) who labelled them ocean and stream types. Ocean type fish exhibit a short freshwater residence, usually migrating to sea within six months of emergence. Stream type fish migrate to sea in the spring of their second year. In some northern stocks, juvenile chinook may remain in freshwater for two or more years. Stream type life histories are found in rivers, north of 56°N and in populations that spawn in the upper reaches of rivers that penetrate long distances inland such as the Fraser and Columbia rivers. Between 56°N and the Columbia River both life history patterns are present. South of the Columbia River the ocean type life history dominates (Healey 1991; Taylor 1991) (Figure 12). Healey (1991) associated the stream type life history variant with adult spawning migrations in the spring and summer and the ocean type variant with adult spawning runs in summer and winter. This generalization breaks down, however, on the California, Oregon and Washington coasts where the spring chinook runs are often comprised of a significant proportion of fish with ocean type life histories. For example, in the Rogue River, 95 percent of the adult spring chinook exhibit the ocean type life history pattern (Nicholas and Hankin 1989).

Intrapopulation life history patterns observed in chinook salmon (e.g., Reimers 1973; Schluchter and Lichatowich 1977; Carl and Healey 1984; Nicholas and Hankin 1989) and the geographic distribution of those life histories (e.g., Taylor 1990a; Healey 1991) might be interpreted as evidence for adaptive developmental plasticity. Even though evidence for a genetic basis for local life history traits is accumulating (e.g., Gharrett and Smoker 1993a; Carl and Healey 1984), overall,

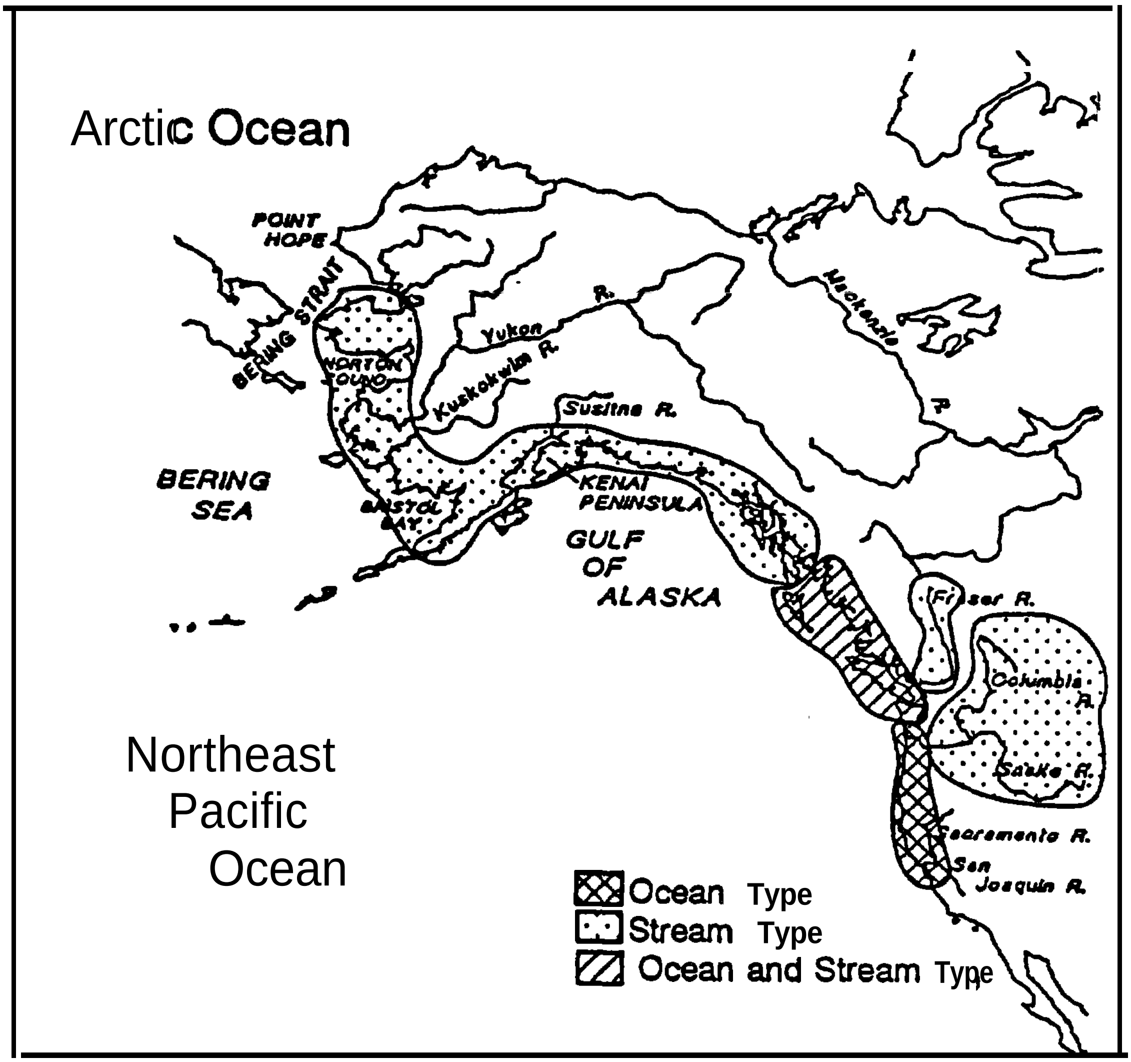


Figure 12. **Distribution of stream and ocean type life histories in chinook salmon. (Based on data from Taylor 1990a)**

the evidence that life history traits of local populations are adaptive is largely circumstantial (Taylor 1991).

Life history traits may represent developmental conversion or environmental modulation (Smith-Gill 1883). Life history is the product of developmental conversion if the salmon's possible developmental pathways are genetically programmed to respond to environmental cues. Life history traits are environmentally modulated when they are simply a passive response to environmental variability.

Based on a review of the geographic distribution of the stream and ocean type life history patterns in relation to environmental factors, Taylor (1990a) concluded that variability in the age at seaward migration in chinook salmon is a response to the environment. Stream or ocean type life history is a response to variability in growth opportunity (temperature and photoperiod) and distance from the sea. He concluded life history variability represents in part environmental modulation of the timing of smolting, however, he conceded that this mechanism might be constrained by selection for size at migration.

Support for Taylor's (1990a) hypothesis regarding environmental modulation of life history type through growth opportunity comes from a study of juvenile chinook salmon in the Situk River, Alaska (Johnson et al.1992). Even though the Situk River is above 56°N, the theoretical northern limit of the ocean type life history, the dominant juvenile life history was the ocean type — most juveniles migrated to sea by November of their first year. Growth opportunity might have been enhanced by warm river temperatures due to the influence of Situk Lake.

Taylor's (1990a) conclusion regarding the environmental modulation of chinook salmon life histories was challenged following a series of experiments on the genetic control of the expression of stream and ocean type life histories in chinook salmon (Clarke et al. 1992). The experiments demonstrated developmental conversion in chinook salmon populations that normally exhibit the stream type life history. When juveniles from a stream type population, were exposed to short day length at first feeding followed by exposure to long day length, they grew rapidly and developed seawater tolerance similar to the ocean type pattern. When juveniles from the same population were exposed to long day length at first feeding, their growth was slower and consistent with stream type life history, Juvenile chinook salmon from a population that normally exhibited the ocean type life history did not show this developmental conversion — they grew rapidly regardless of day length at first feeding. Fry from crosses of both reciprocal stream type-ocean type hybrid groups displayed the ocean type pattern. This suggests that ocean type life history is dominant and that photoperiod responsiveness may be under Mendelian genetic control (Clarke et al. 1992).

In another controlled laboratory experiment, juvenile chinook salmon reared under common environments in the laboratory, exhibited phenotypic variability in aggression, growth and positive rheotaxis among several populations (Taylor 1990b). The differences between populations were functionally consistent with each population's normal freshwater life history (stream or ocean type). Based on this observation, Taylor (1990b) argued that the observed phenotypic variability represented adaptive divergence within the species. Increased fitness of functionally related life history traits could have resulted in selection for those traits.

As with many phenotypic traits, juvenile migration is probably under both genetic and environmental control.

Within a given watershed and population of chinook salmon the distinction between stream and ocean type life history patterns blurs into a diversity of more complex patterns. Reimers (1973) identified five life history patterns in Sixes River fall chinook based on timing of downstream migration, the extent of estuarine rearing and timing of ocean entrance. Using criteria similar to Reimers (1973), Schluchter and Lichatowich (1977) identified eight life history patterns in spring chinook salmon from the Rogue River. Carl and Healey (1984) identified three life history patterns for juvenile fall chinook salmon in the Nanaimo River. Genetic differences in juveniles exhibiting the different life histories were demonstrated (Carl and Healey 1984). Stream type life histories may show variation in migration and rearing distribution within tributaries and between tributaries and the mainstems of larger rivers (e.g., Lindsay et al. 1986 and 1989; Fast et al. 1991; Burck 19931.

From the foregoing discussion of chinook salmon life histories the following salient points can be summarized:

- Juvenile life history patterns are probably neither entirely determined by environmental modulation or developmental conversion. Life histories probably result from a combination of the two.
- The ocean type life history pattern is dominant.
- Stream type life history is determined in part by photoperiod at emergence and stream temperatures.
- Under healthy habitat conditions, a population of juvenile chinook will exhibit several variations of the stream and/or ocean type life histories.

TEMPLATE DESCRIPTION

General Description of Abundance, Habitat and Life History of Chinook Salmon in the Columbia River

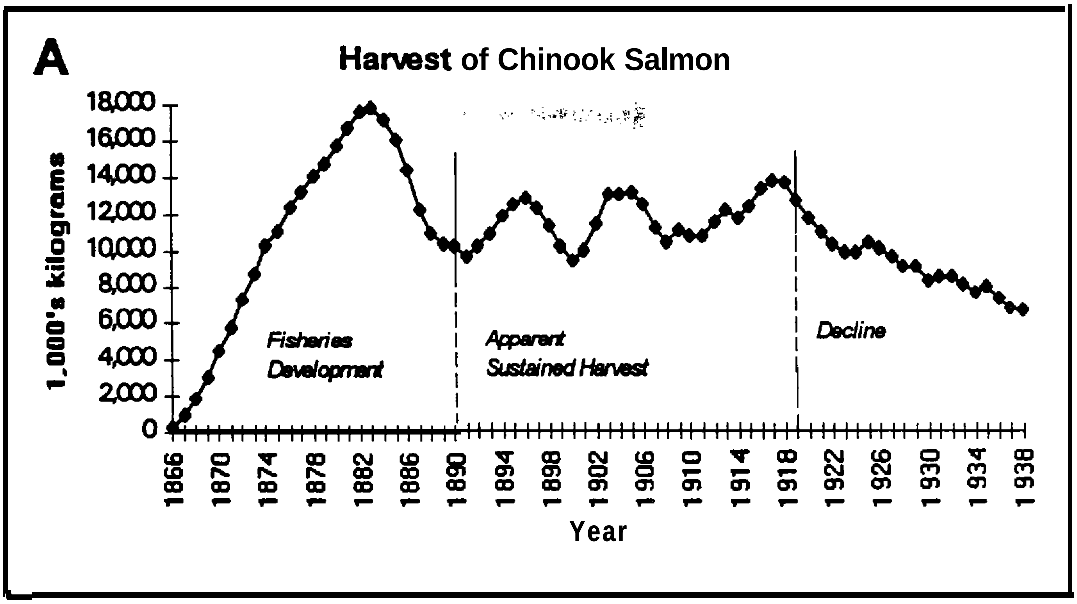
Predevelopment Abundance of Salmon

The NPPC (1986) used several different approaches to estimate predevelopment abundance of Pacific salmon in the Columbia River which yielded a range of annual run sizes of 8-35 million salmon and steelhead. Following an assessment of the various methods, the NPPC narrowed the range to 1 O-l 6 million fish (NPPC 1986 p. 14). Included in that total were 4.7 to 9.2 million chinook salmon (NPPC 1986, Table 6). Those point estimates of abundance give an indication of the size of the predevelopment runs into the Columbia River but not the natural variation in abundance. Continuous estimates of abundance through the early decades of the commercial salmon fishery are not available. However, the size of the commercial harvest can be used as an index of the long-term trend in abundance.

Commercial Harvest

The commercial harvest and export of salted salmon began in the 1820s and grew modestly to 2,000 barrels by the early 1860s. Intensive fisheries did not begin until cannery technology reached the Columbia River in 1866 (Craig and Hacker 1940). After 1866, the catch of salmon and the amount of fishing gear employed in obtaining that catch increased rapidly (Figure 13). The harvest of chinook salmon peaked in 1883 at 42,799,000 lbs. (Beiningen 1976). The catch declined from that peak and entered a period of sustained harvest fluctuating around an average catch of about 25 million pounds for the next 30 years. About 1920, the catch went into a decline that continued through to the end of the template period (Figure 13).

In the final decades of the 19th Century and the early decades of the 20th Century, the salmon canning industry shifted locations and species to maintain production. The industry shifted northward as the salmon in the southern rivers were depleted (DeLoach 1939). In addition, species such as chum, pink and coho salmon which were considered “inferior” were canned in increasing numbers when the preferred chinook and sockeye salmon, failed to satisfy demand (DeLoach 1939). Chinook salmon always brought the highest price (DeLoach 1939) and the chinook salmon that entered the river in spring and early summer were of highest quality (Hume 1893; Cobb 1930; and Craig and Hacker 1940).



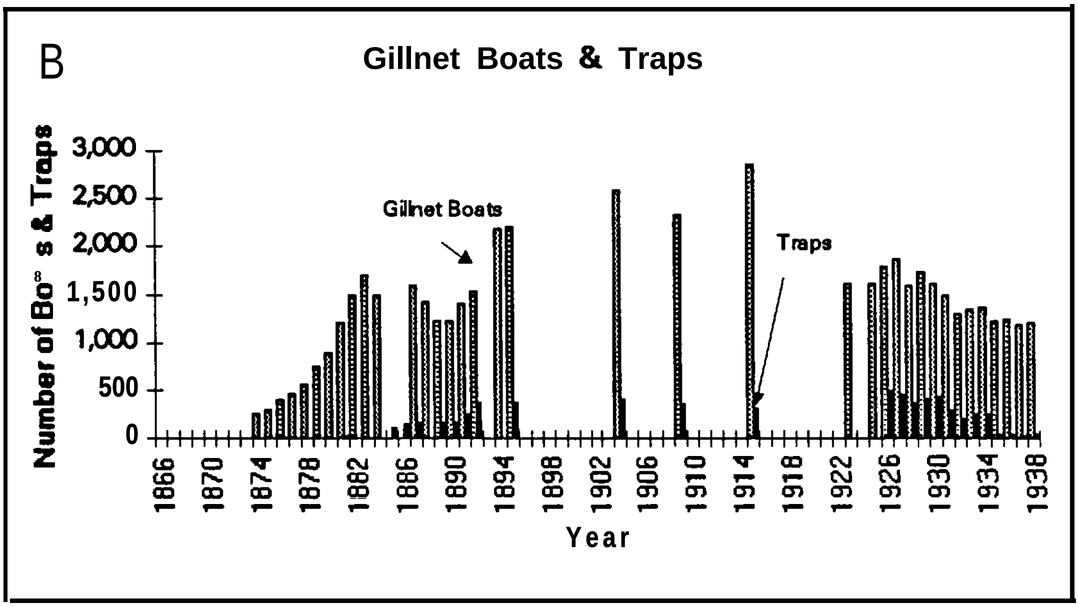


Figure 13. Trend in chinook salmon abundance in the Columbia River during the template period. (A) is the five year running average of chinook salmon harvest. (B) describes the growth in the number of gillnet boats and traps employed in the fishery. (Data from A – Beiningen 1976 and B – Smith 1979).

The harvest of chinook salmon in the Columbia River underwent important qualitative changes which are not evident from an examination of the harvest data shown in Figure 13. The canneries prized the spring and early summer run of chinook salmon and targeted those fish during the early years of the fishery. In 1892, 95 percent of the harvest was taken from the spring and summer run. By 1912, the spring/summer run fish in the harvest dropped to 75 percent as more fall chinook were harvested, and by 1920, fall chinook salmon made up 50 percent of the catch (Smith 1979) (Figure 14). Between 1892 and 1920, the fishery for Columbia River chinook salmon appeared to be in a period of relative stability, however, underneath the catch statistics a major life history shift was taking place (Figures 14 and 15). The spring/summer run was rapidly declining. Production quantity was maintained through a qualitative shift in the fishery to fall chinook salmon. Fall chinook were not as desirable for canning because of their lower oil content and color (Smith 1979). Because of the shift in the fishery from spring/summer to fall chinook, Craig and Hacker (1940) suggested that a real decline in chinook salmon abundance in the Columbia River began in 1911. They attributed the decline to overharvest and habitat degradation.

Early Habitat Degradation in the Columbia Basin

One of the important causes of habitat degradation in the study area (Cascade rainshadow) in the late 19th Century and early part of this century was irrigated agriculture. Irrigation impacted anadromous salmonids in three ways: the loss of migrating juveniles in unscreened irrigation ditches, the dewatering of tributaries which eliminated habitat and blocked migration of juvenile and adult salmon, and the construction of dams to divert irrigation water into ditches which also blocked migration. The problems stemming from the construction of irrigation systems and power dams in the tributaries were serious and they were mentioned frequently in the early reports of salmon management institutions. As early as 1890, the Oregon State Board of Fish Commissioners reported the loss of juvenile salmon in irrigation ditches and requested legislation to prevent such losses (Oregon State Board of Fish Commissioners 1890 and 1892). The persistence of salmon losses in unscreened irrigation ditches was described by the Oregon State Fish and Game Protector in his report to the legislature in 1896. Again, in 1901, the annual report for the Oregon Department of Fisheries contained this statement:

> *"Another and more serious reason for salmon not entering many of the streams of eastern Oregon and Idaho in such large numbers as they did years ago, must be attributed to the settler. This part of the country being dry, requiring irrigation during the summer months, dams have been built on nearly all the small streams, water being taken from them and carried in ditches for miles for this purpose, thus destroying much of the best spawning grounds."*

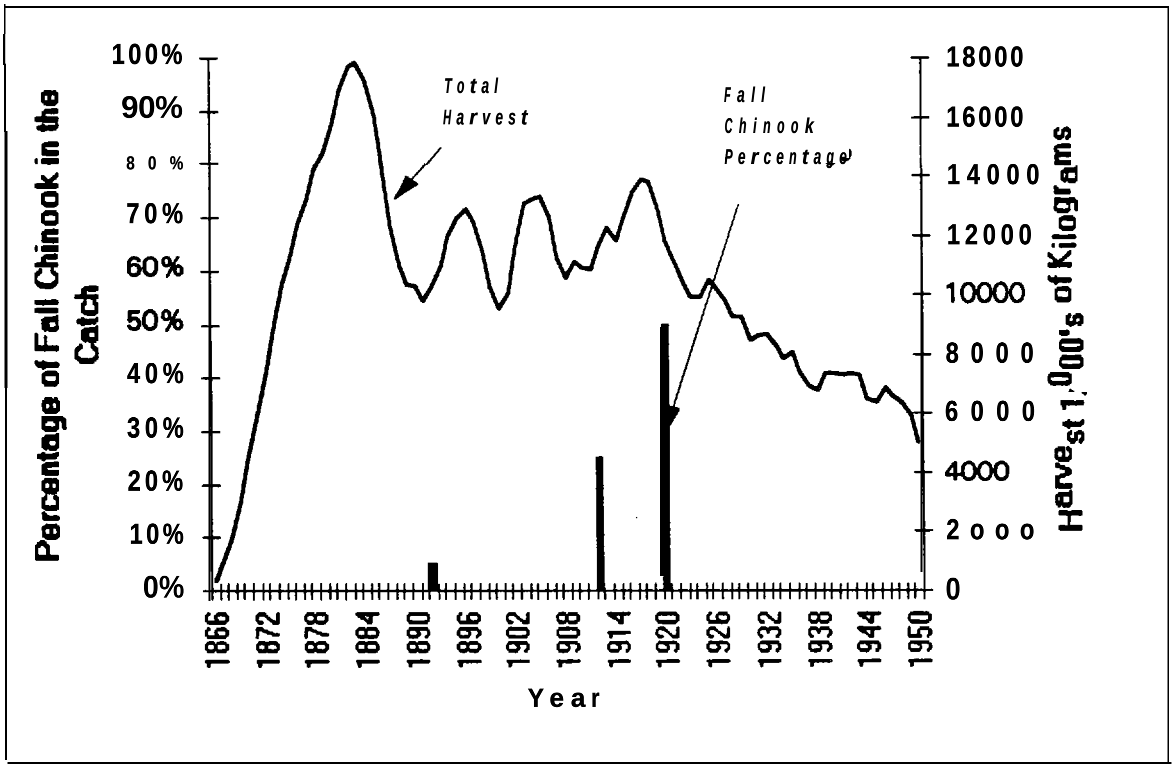


Figure 14. Five year moving average of chinook salmon harvest in the Columbia River and the percentage of the catch made up of fail chinook in 1892, 1912 and 1920. (From Beiningen 1976 and Smith 1979)

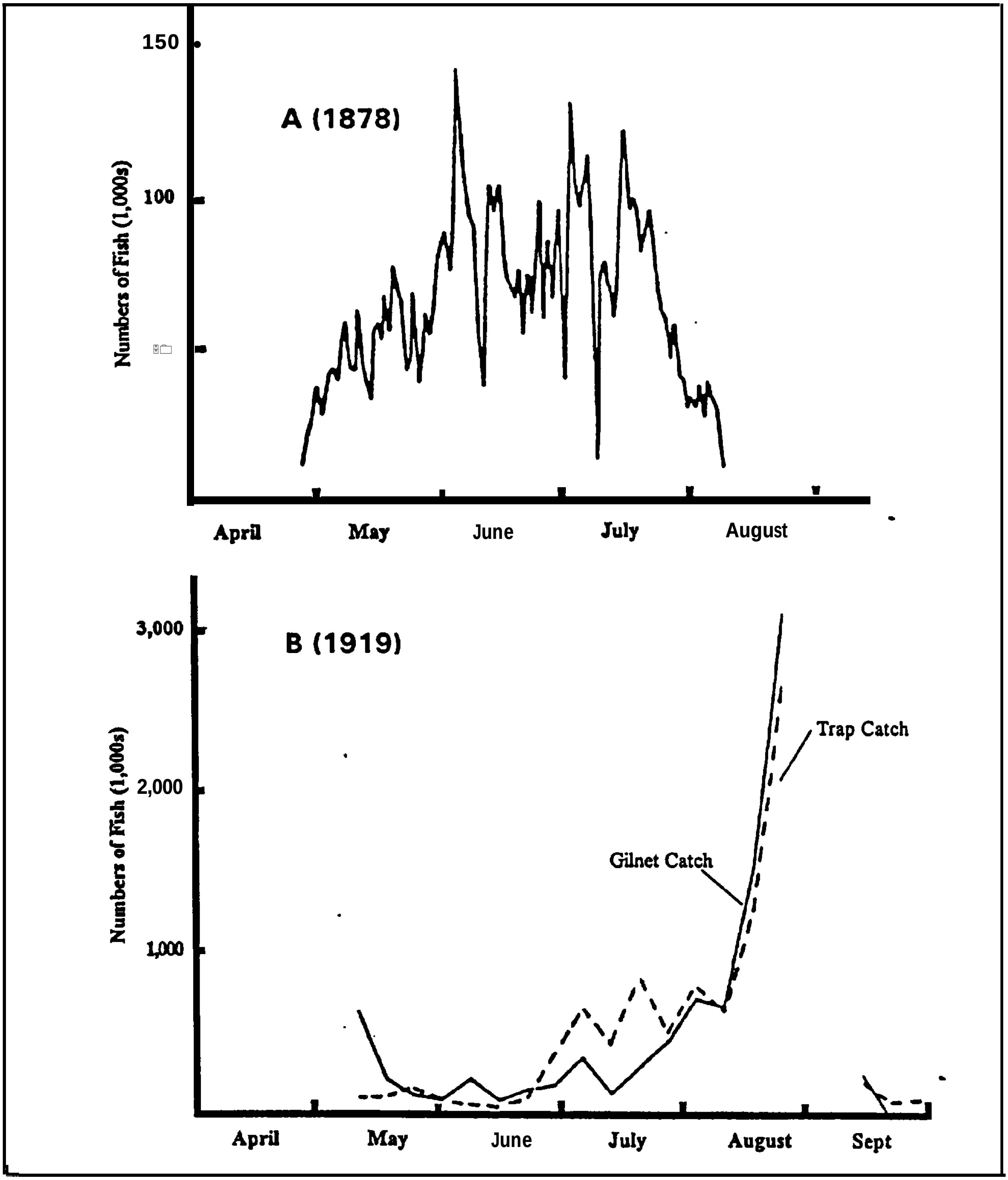


Figure 15. Comparison of the seasonal distribution of the chinook harvest in the Columbia River in 1878 (A) and 1919 (B). (From Whitney and White 1984)

The Washington State Department of Fisheries and Game (1904) also identified irrigation withdrawals as a major problem affecting young salmon in the eastern part of that state.

Irrigation was just one of many activities that contributed to the degradation of salmon habitat. Gold mining, cattle and sheep grazing, timber harvest, dams for hydropower all contributed to the decline of salmon habitat. The growth and development of all these activities are summarized in NPPC (1986).

The total habitat loss and degradation in the early decades of this century was extensive. The 1932 biennial report of the Oregon Fish Commission (OFC) describes a color map of the Columbia Basin prepared by the Commission staff over a 15 year period. The map apparently showed that 50 percent of the most productive spawning and rearing areas within the Columbia Basin had been lost due to dams for irrigation and power (OFC 1933). While the intensity of the harvest probably contributed to the decline in spring and summer chinook prior to 1940, habitat degradation cannot escape being listed as a major contributor to that decline.

When they occur together, the effects of habitat degradation and overharvest are not independent. As habitat is degraded, harvestable surplus declines which intensifies the effect of poorly regulated and intensive fisheries. A fishery operating at intensive but sustainable levels can quickly shift to overharvest when habitat degradation is allowed to occur.

Life Histories of Columbia River Chinook Salmon

As mentioned earlier, the distribution of the catch among the spring, summer and fall races of chinook salmon shows a qualitative shift in life history in the early decades of the commercial fishery (Figures 14 and 15). The harvest of spring and summer chinook declined and the catch of fall run fish increased. In addition to the shift in relative abundance of different races of chinook salmon, the size and age structure of chinook salmon were also declining as early as the 1920's (Ricker 1980).

The timing of juvenile migration to the sea is an important life history trait that shows less annual variability than, for example, adult abundance. The relatively low within-population variability in the seasonal migration peaks might indicate that timing has high survival value (Lichatowich and Cramer 1979). Migration timing may be tuned to flow conditions in the subbasin and mainstem that are favorable to safe transport downstream. Migration may also be timed to ensure that juveniles arrive in the estuary or ocean when food is abundant.

Juvenile chinook salmon were collected by beach seine in the lower Columbia River in 1914, 1915 and 1916. Although interpretation of these data in terms of juvenile migration has several problems (Rich 1920), it is the only information available. The data suggest that the migration of ocean type juveniles extended over a large part of the spring, summer and fall (Figure 16). Rich (1920) suggested that the extended period of juvenile presence represented movement of successive populations of juveniles from different tributaries. He speculated that the late migrating fish were from tributaries increasingly further up stream. Yearling chinook were a small part of the total juveniles captured.

The age distribution of returning adults and their juvenile life histories (ocean or stream type) were determined in the early decades of this century for the Columbia River (Rich 1925) and for the Sacramento and Klamath rivers (Snyder 1931) (Figures 17 and 18). Unfortunately, the life history data for spring/summer chinook in the Columbia River may not reflect the predevelopment and pre-

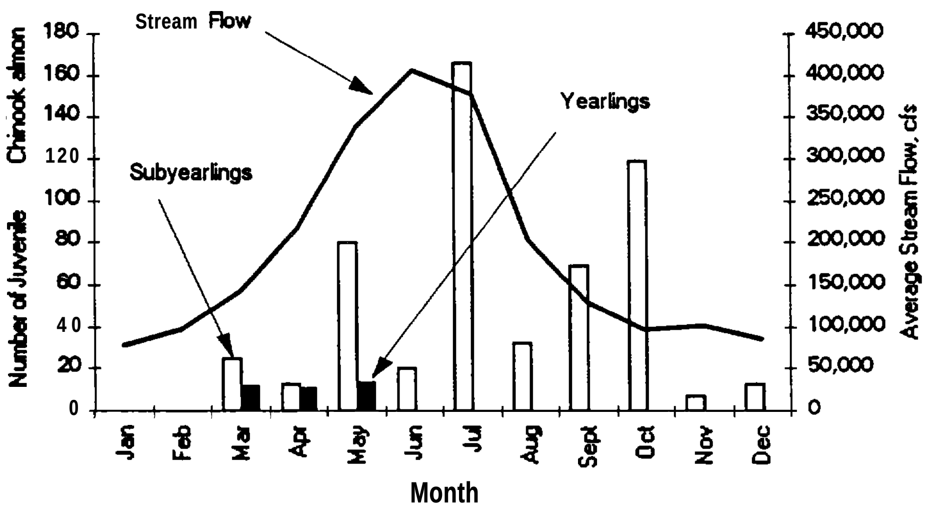
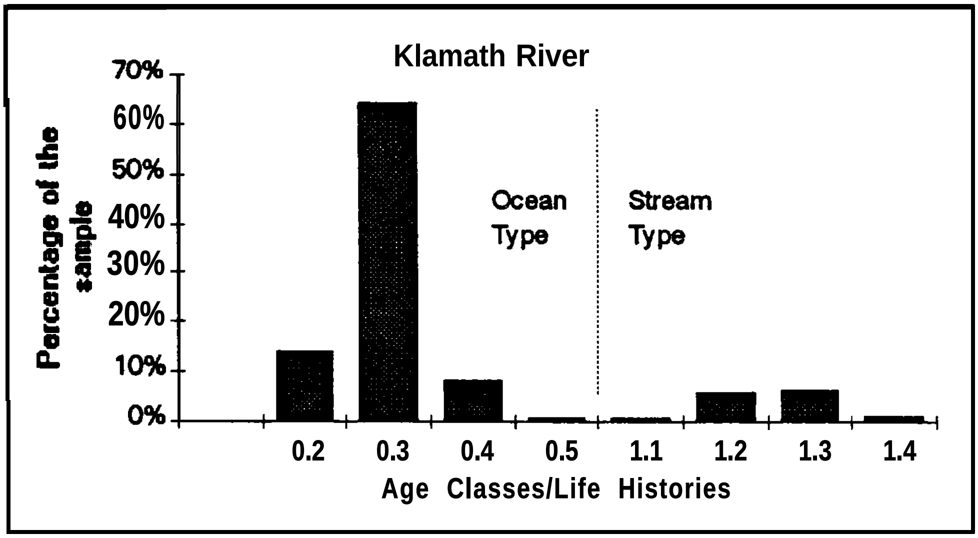


Figure 16. Average monthly catch of juvenile chinook salmon in the lower Columbia River 1914 to 1916. Average monthly stream flow at The Dalles for 1916. (Salmon data from Rich 1920, Flow data from Hydrosphere, Inc. 1990)

commercial harvest conditions. The juvenile life histories of the Columbia River chinook salmon were obtained in 1919-1923 or after the spring/summer chinook runs had already experienced significant declines in abundance (Figures 14 and 15).



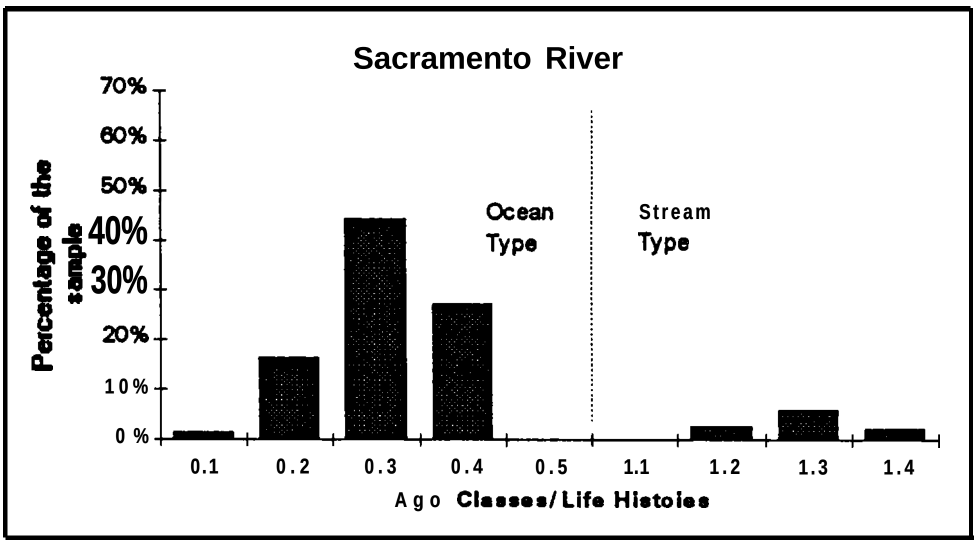


Figure 17. Age distribution of adults and juvenile life histories of chinook salmon in the Sacramento River for 1919 and 1921 and the Klamath River for 1919, 1920 and 1923. See text for explanation of age class/life history designation. (From Snyder 1931)

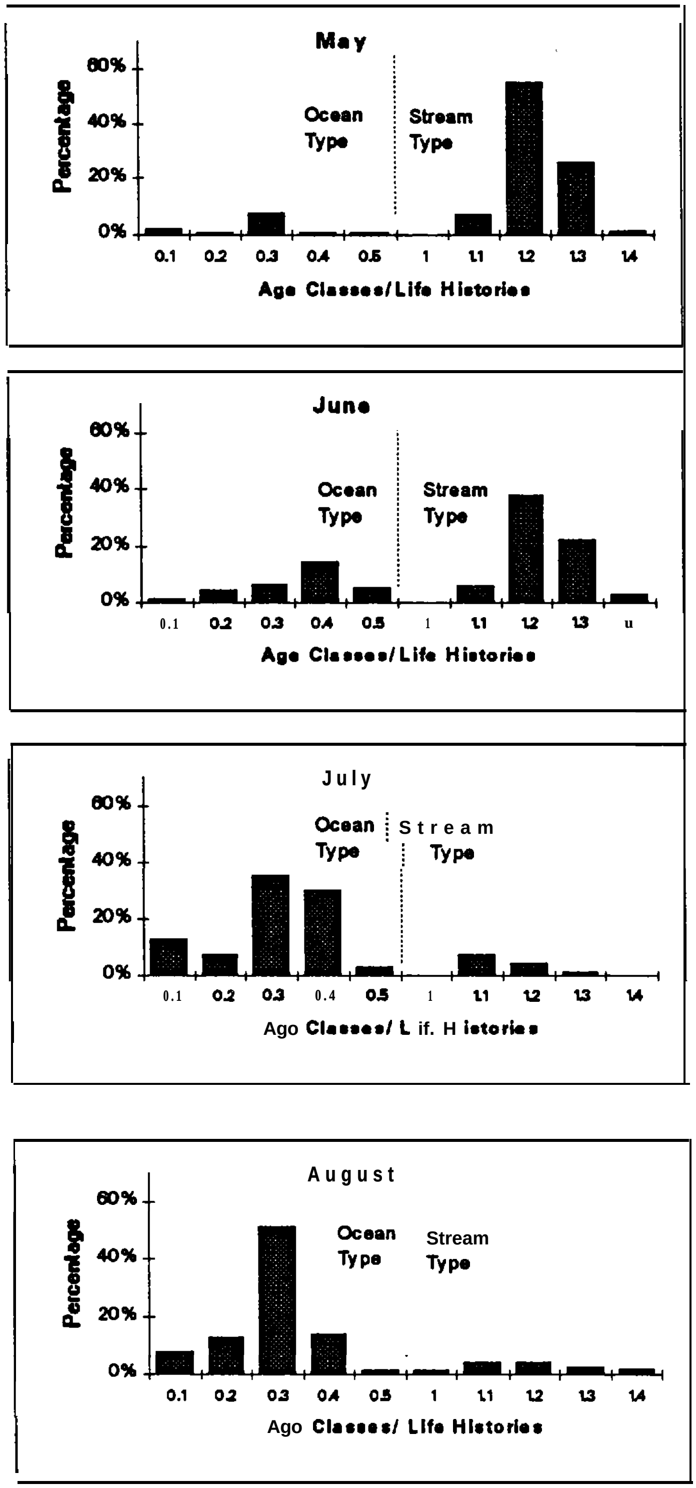


Figure 18. Average monthly age distribution and juvenile life histories of adult chinook salmon collected in the lower Columbia River May through August in 1919. See text for explanation of age class/life history designation. (From Rich 1925)

Age and life history designation in Figures 17 and 18 follow this method: The number of winters spent in freshwater, excluding egg incubation, are designated by the numeral to the left of the period. The number to the right of the period indicates the number of winters spent in saltwater. Total age is the sum of the two numbers plus 1. Ocean type life history is designated by a 0 to the left of the period. Age classes and juvenile life histories (ocean and stream type) were determined from an analysis of scales removed from adult fish.

The ocean type life history was important in the Sacramento and Klamath rivers. The juvenile life histories cannot be separated by race because data from those two rivers are composite samples including spring/summer/fall run fish. However, of 35 fish sampled from the spring run in the Klamath River, 29 exhibited the ocean type life history pattern (Snyder 1931 p. 23).

In the Columbia River, the juvenile life histories of returning adults changed through the migratory season (Figure 18). Monthly averages of the histories are shown in Figure 18. In daily samples, the ocean type life history pattern was observed on as many as 38 percent of the scales collected on May 27 and 63 percent of the fish sampled on June 24-25 respectively (Table 1). However, the stream type life history dominated in May and June and ocean type life history dominated in July and August. This led to the conclusion that spring run fish have the stream type life history and fall run fish have the ocean type life history pattern (Rich 1925) which has persisted until the present (Healey 1991).

In the Columbia and Klamath rivers, chinook salmon migrated downstream to sea throughout the year (Rich 1920), so the distinction between ocean type and stream type life histories was not always clear to early workers (Rich and Holmes 1928; Synder 1931). In fact, the majority of the chinook salmon scales analyzed showed neither a typical stream or ocean type life history pattern. The fish spent part of their first year in freshwater and part in saltwater (Rich and Holmes 1928). Because of this uncertainty, some late migrating, ocean type fish might have been classified as stream type. This is particularly true for the fish sampled in May and June (Table 1) because conventional wisdom held that the spring run fish had the stream type life history.

It must be emphasized that the data in Table 1 and Figure 18 were collected in the Columbia River after the spring/summer run was in significant decline (Figure 15). Factors creating that decline — habitat destruction in particular — may have selectively reduced specific life history patterns and distorted the importance of the remaining life histories.

Table 1. Percentage of ocean and stream type life histories observed on scales of adult chinook salmon returning to the Columbia River in 1919. (Data from Rich 1925)

Month	Sample Date	Percentage Ocean Type	Percentage Stream Type
May	IO	2.4	97.6
	13	10.7	89.3
	16		100.0
	17-18	9.3	90.7
	27	38.7	61.3
	30-31	6.0	94.0
June	10	35.0	65.0
	16	9.1	90.9
	17	17.3	82.7
	24-25	63.0	37.1
July	3	88.3	11.8
	7	85.6	14.1
	16	77.6	22.4
	28	98.0	2.0
August	5	75.0	25.0
	6	92.6	7.4
	22	92.6	7.4
September	12	87.4	12.7

Yakima River

Abundance of Chinook Salmon. Robison (1957) divided his estimates of the abundance of salmon in the Yakima River into four periods: Prior to 1847, 1875-1905, 1905-1930 and 1930-1949.

- Prior to 1847. The Native American harvest of salmon in the Yakima River was estimated to be 160,000 adult fish. Assuming the actual run to the river was three times the catch, the total run of salmon would have been about 500,000 fish (Robison 1957). The predevelopment abundance of Pacific salmon was also back calculated from the total area of spawning habitat and the area needed by a single pair of spawning chinook salmon. Dividing the total area by the area occupied by a single pair and assuming full seeding led to an estimate of 500,000 salmon. Species were not differentiated.

- 1875-1905. Rapid development in the Yakima Basin including intensive development of irrigation, logging, hydraulic mining, over-harvest and neglect by management agencies contributed to a drastic decline in abundance of salmon (Robison 1957). During this period, the catch declined to about 20,000 salmon annually. Another estimate put total abundance by the end of the century at about 50,000 salmon (Davidson 1965).

- 1905-1930. After 1905, the catch declined annually until 1930 when it amounted to about 1,000 spring chinook. The major salmon fishery on sockeye salmon was eliminated by 1905 (Robison 1957).

- 1930-1949. The catch ranged from 1,000 to 1,500 spring chinook salmon.

Smoker (1956 reported in Fast et al. 1991) estimated the historic size of the Yakima River spring chinook population at 250,000. CTYIN et al. (1990) reviewed historic abundance of spring chinook in the Yakima Basin and concluded that 90% of the run was lost between 1850 and 1900.

The early estimates of abundance of chinook salmon in the Yakima River were obtained through indirect methods so the specific numerical value must be used with caution. However, a reasonable inference is that the run of chinook salmon was large, in the range of 100,000 to 300,000 fish. The chinook population underwent significant decline before 1900.

Habitat. The extent of early habitat degradation in the Yakima River is difficult to establish with any accuracy, however, there is evidence to suggest that the quality of salmon habitat declined significantly by the later decades of the 19th century and continued to decline through the early decades of this century. The timing of habitat destruction is consistent with the timing of the decline in abundance of chinook salmon. Salmon habitat was altered by logging, mining and grazing, however, irrigation probably had the biggest impact on salmon production and productivity.

The first irrigation ditch in the Yakima Basin was constructed in 1853, and the first ditch of large size was finished in 1875 (Kuhler 1940). Construction of irrigation ditches continued through the 1880s. Passage of legislation favorable to the development of irrigation projects enhanced construction activity in the decade 1890 to 1900 (Kuhler 1940). Between 1905 and 1930 the acreage under irrigation increased from 121,000 to 203,000 (Robison 1957) and by 1947, 354,877 acres were being irrigated (Davidson 1965). It was not until 1930 that efforts were initiated to protect salmon from unscreened irrigation ditches (Davidson 1965).

Irrigation had its biggest effect on salmon habitat in the middle and lower Yakima River. The loss of salmon fry in irrigation ditches, the dewatering of streams and the migration blockage have all been attributed to irrigation in the closing decades of the 19th Century and the early decades of the 20th Century. However, with one exception, we found no published studies that quantified the impact of the early, unscreened irrigation diversions on salmon.

In 1920, Dennis Winn, the field superintendent for hatchery work on the Pacific Coast for the U. S. Bureau of Fisheries, was directed to investigate the effects of irrigation on salmon and steelhead in the Yakima River. Although Mr. Winn made his inspection trip during the winter after the ditches had been shut down, and few juvenile fish were migrating, he still found evidence of significant numbers of salmon in the ditches *(Pacific Fishermen 1920).* In his report, Winn also discussed a study that attempted to quantify the loss of juvenile salmon in unscreened irrigation ditches in the Yakima River. The study was conducted by biologist Frank Bryant in July, 1916. Bryant subsampled a total of 200 acres of irrigated land after it had been watered — the fishes stranded on the 200 acres were counted. He found 20 fish/acre or a total of 4,000 fish in the 200 acres of which 90% were migrating salmon. Extrapolated to the entire basin, Bryant estimated 4,500,000 migrating salmon were lost with each watering (*Pacific Fisherman* 1920). The extrapolated estimate of total losses needs to be viewed with caution; however, it does indicate a problem of significant proportions.

The location of major irrigation diversions in the Yakima River (Figure 19) suggest that the progeny of chinook salmon that spawned in the middle and upper reaches of the Yakima River were most vulnerable to unscreened diversions. Spring and summer chinook spawned in the middle and upper basin. Bryant's study was conducted in fields irrigated by the Hubbard Ditch which was located just below the confluence of the Yakima and Naches Rivers. The mortalities counted by Bryant would have been juvenile spring or summer chinook.

In the upper Yakima River, the major impacts on salmon habitat came from grazing and fires. Many of the fires were set by sheepmen to improve the range (Smith 1993). The extent of the burns near the turn of the century caused the U. S. Geological Survey to conclude that the watershed had been degraded to the point of possibly threatening the water supply for irrigation in the basin (Plummer 1902). The number of sheep in the basin grew rapidly prior to 1900 — 5,000 in 1879 to 16,000 by 1889 and 261,000 by 1899. After the turn of the century large scale grazing declined (Kuhler 1.940).

It's clear that habitat degradation was a major factor in the decline of spring and summer chinook salmon in the Yakima Basin. Habitat degradation was severe enough in the later decades of the 18th Century to suggest that it contributed to the early decline in the commercial fishery for spring and summer chinook salmon discussed earlier in this report.

Life History. Life history of juvenile chinook salmon in the Yakima River can be inferred from the records of salmon observed in irrigation ditches. Those data were collected by a Washington Department of Fisheries employee, Ernie Brannon, in 1929 and 1930 and recorded in his work diary (Brannon 1929 and 1930). In some cases, Brannon made visual estimates of the number and species of fish in an irrigation ditch. In other cases, he captured the fish and counted them.

Unfortunately, the data do not extend over an entire year or migration season (Figure 20). In 1929, the irrigation ditches were sampled from mid-May to mid-June. The largest number of juvenile chinook salmon was observed on June 9 in the Sunnyside Canal. The 1930 data set, which did not begin until mid-July, shows large numbers of juvenile chinook salmon in the ditches in July. Fewer fish were observed in August and September. Movement of juvenile salmon into the irrigation ditches suggests they were actively migrating downstream. Juvenile

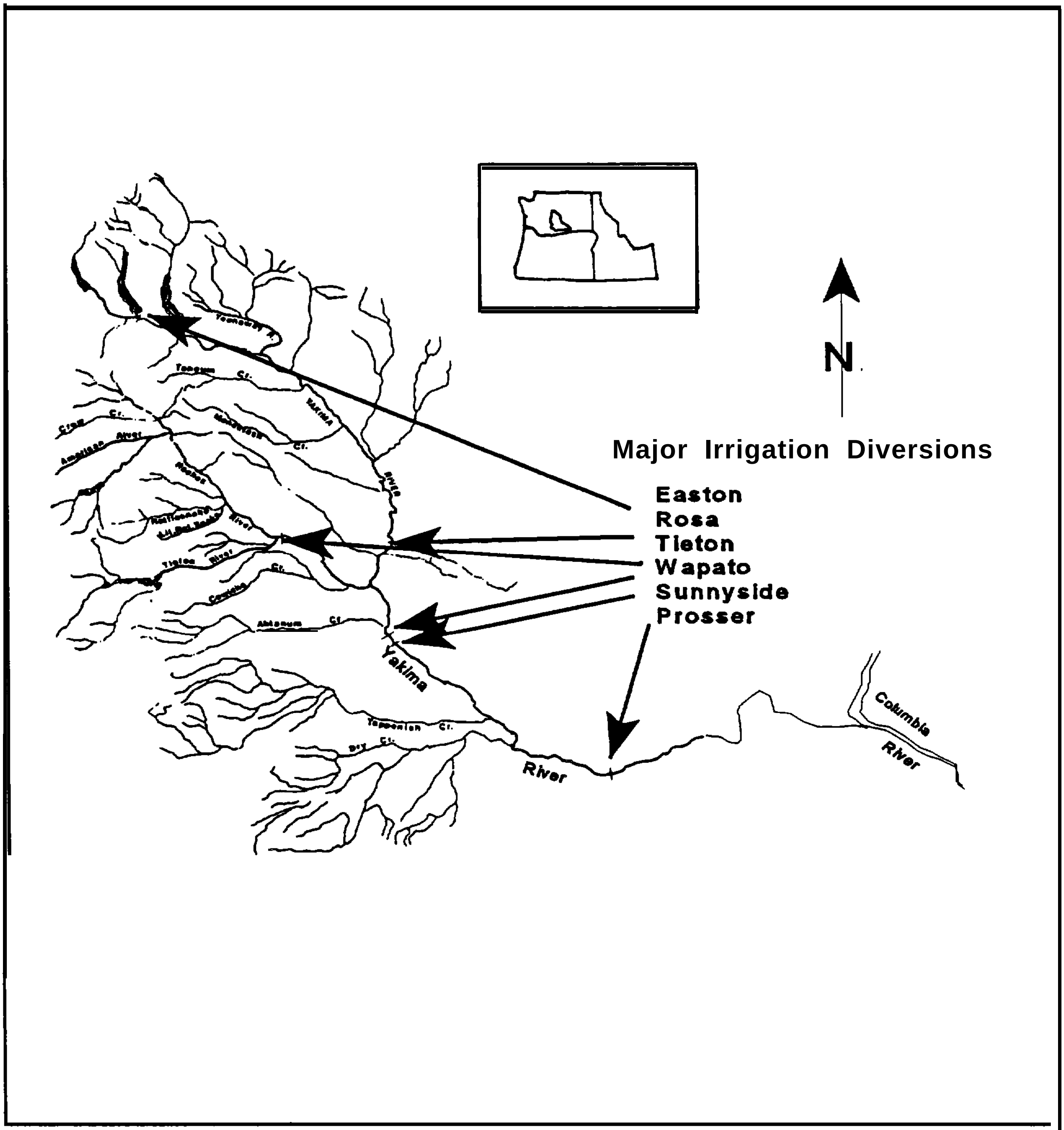
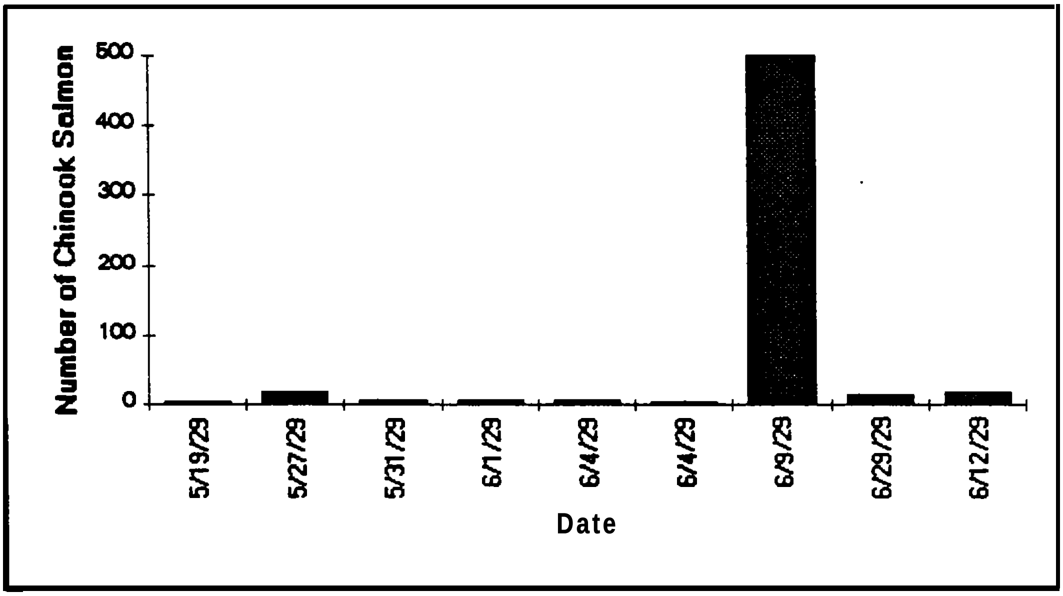


Figure 19. Location of major irrigation diversions in the Yakima Basin. (From U. S. Department of the Interior 1982)



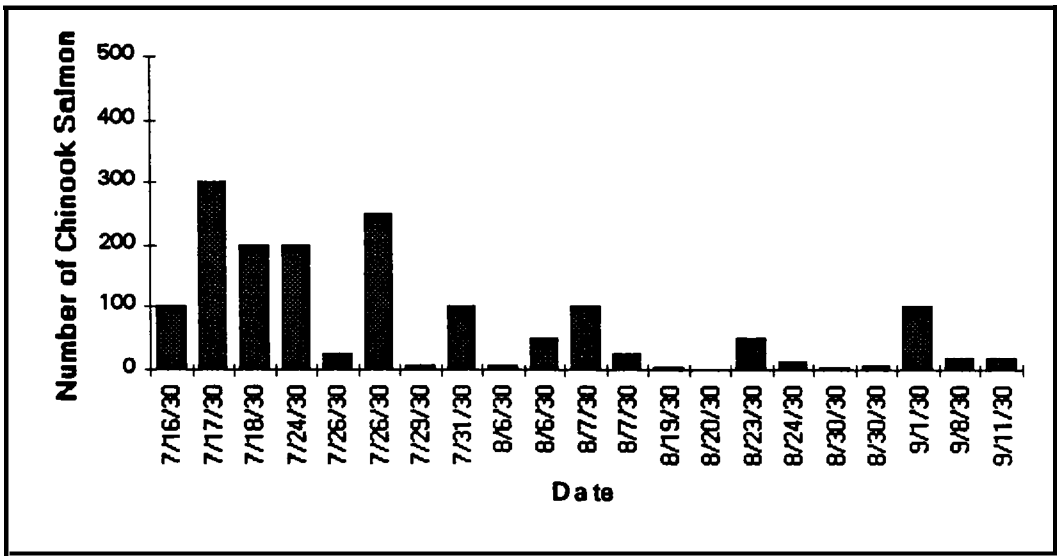


Figure 20. The number of juvenile chinook salmon observed in irrigation ditches in the Yakima Basin in 1929 and 1930. The data are combined observations from several ditches. (Data from Brannon 1929, 1930)

chinook salmon found in the ditches were 8 cm or larger which is consistent with the size of migrating smolts (Figure 21). Juvenile chinook salmon in Oregon's coastal basins may migrate to the sea as small as 7 cm. Based on an analysis of scales removed from adult chinook salmon, the size at ocean entrance of juveniles that survived to maturity was generally greater than 10 cm and between 10 cm and 14 cm (Nicholas and Hankin 1989). It is assumed that chinook salmon captured in irrigation ditches in July were subyearlings and they would grow at least another 2 cm in the mainstem Columbia River and estuary before entering the sea. Yearling fish would have left the system earlier in the year. Sizes obtained in July-September indicate high growth potential which also suggests an ocean type life history pattern.

Bryant conducted his 1916 study of the losses of juvenile salmon in unscreened ditches in July because that was the peak of downstream movement at that time *(Pacific Fisherman* 1920). Haggart (1928) also observed a peak in migration in mid-summer. Even when the shortcomings of the data on life history are considered, it seems clear that juvenile spring/summer chinook were migrating in the Yakima River through the summer months. Juvenile chinook salmon migrating downstream during the summer would have suffered severe mortalities from unscreened irrigation ditches. In later years, the juvenile chinook salmon encountered lethal water temperatures in the lower river in July and August (see patient description).

Watson (personal communication; Bruce Watson, YIN, 1992) concluded that juvenile spring chinook salmon in the Yakima River historically exhibited six life history patterns (Table 2) including the ocean type. He based his conclusion regarding the ocean type life history on two pieces of historical information: 1) The predevelopment condition of the river channel and its dense riparian cover shaded the stream and that would have kept water temperatures cool; and 2) observations by Haggart (1928) that heavy outmigration of salmon in the Yakima River began in June, peaked in mid-July and continued through mid-September.

Tucannon River

Abundance. In 1989, the state fish commissioner reported that thousands of June migrating (spring run) salmon spawned in the Tucannon River in the 1880s. The run in 1898 consisted of a few dozen fish. (Washington State Fish Commissioner 1898).

Habitat and Life History. Historic information on habitat conditions and life history of chinook salmon was not found.

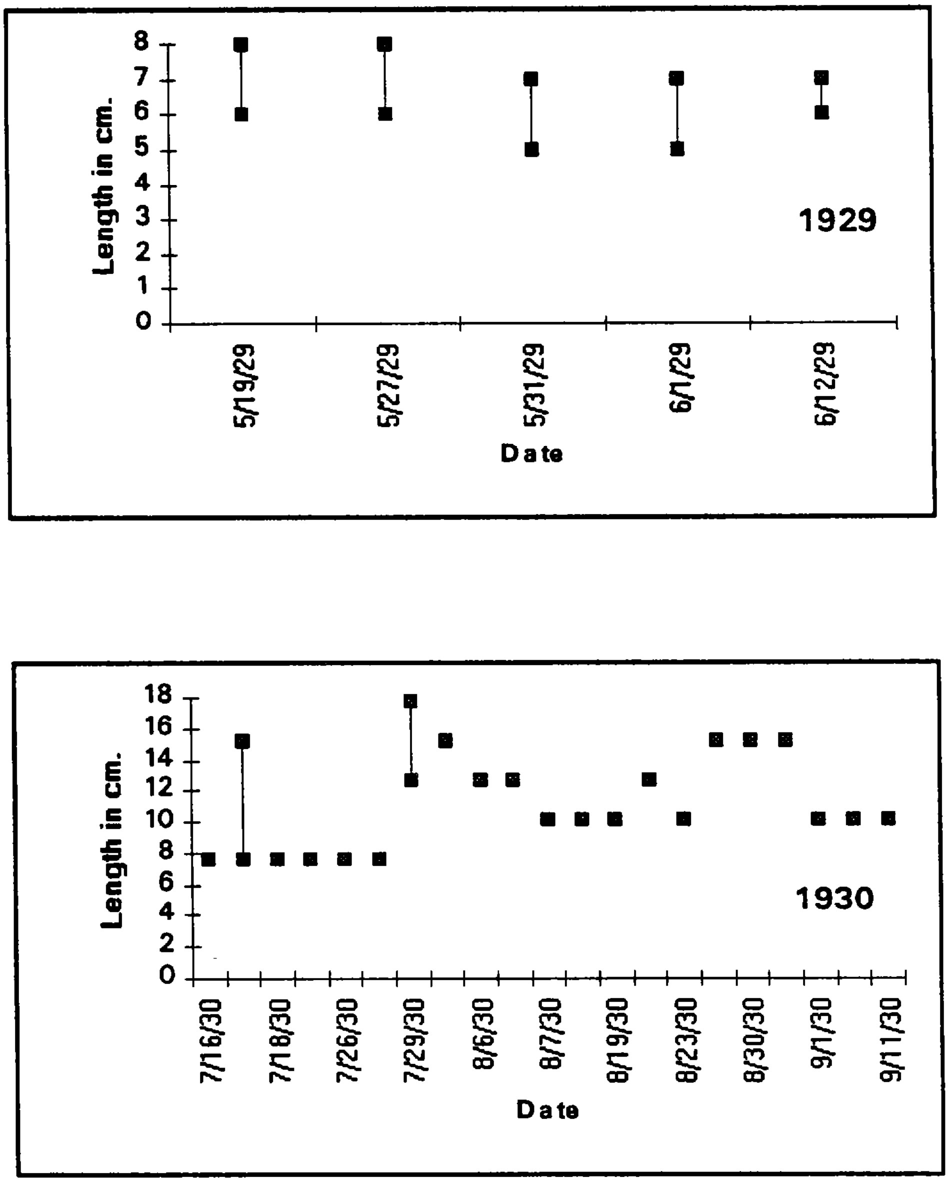


Figure 21. Size range of chinook salmon caught or viewed in irrigation ditches of the Yakima Basin in 1929-30. (From Brannon, 1929, 1930)

Table 2. Six life. history patterns of spring chinook salmon that were historically present in the Yakima River. Pattern No. VI is the ocean type life history. (personal communication; Bruce Watson, YIN, 1992)

No.	Spawning Location	Summer Rearing Location (fry to parr)	Winter Rearing Location (pre-smolts)	Smolt Migration Route (subbasin)	Smolt Age
I	Upper tributaries	Upper tributaries	Upper tributaries	Entire drainage	I+
II	Upper tributaries	Upper mainstem	Upper mainstem	'90% of drainage	I+
III	Upper mainstem	Upper mainstem	Upper mainstem	'90% of drainage	I+
IV	Lower mainstem	Lower mainstem	Lower tributaries	<50% of drainage	I+
V	All drainage units above lower mainstem	All drainage units above lower mainstem	Lower mainstem & associated "sloughs"	<50% of drainage	I+
VI	All drainage units above lower mainstem	Lower mainstem	Not applicable	<50% of drainage	0+

Umatilla River

Abundance. The largest run of chinook salmon in the Umatilla River within the memory of Euroamericans occurred in 1914. In that year, "thousands upon thousands of salmon from spring to fall" were harvested (Van Cleve and Ting 1960 p. 98). No more definitive estimate of historic abundance was found. Native spring and fall chinook and coho salmon were extirpated from the Umatilla River early in this century (CTUIR and ODFW 1990).

Habitat. The extinction of spring and fall chinook and coho salmon followed the construction of Three Mile Dam at RM 3 and the Hermiston Power and Light Dam at Rm 10 in 1914 and 1910 respectively (CTUIR and ODFW 1990). Similar to the Yakima River, irrigation was a major factor in the early degradation of salmon habitat in the Umatilla River. The earliest water right in the Umatilla Basin was granted in 1860 (CTUIR and ODFW 1990). Approximately 40 percent of the recognized water rights were granted prior to the enactment of the 1909 Water Code. More than 4,000 water rights totaling 4,600 cubic feet per second have been granted since then (CTUIR and ODFW 1990). Average stream flows at Umatilla in June, July and August are 121, 21.3 and 35.5 cfs respectively (CTUIR and ODFW 1990). Irrigation diversions dewatered the lower river during the salmon migration season (Van Cleve and Ting 1960).

Life History. No specific observations of life history patterns were found. However, life history can be inferred from anecdotal information. In 1904, the *Pacific Fisherman* published a report from Pendleton, Oregon on a new device to be placed in streams to limit the destruction of juvenile salmon in irrigation ditches. In the same article, the *Pacific Fisherman* (1904 p. 21) stated:

> *"Another fruitful source of trouble is the drying up of streams near their mouth in the summer, due to the exhausting irrigation further up and evaporation. This prevents large numbers of fish which head toward the Columbia River in September from ever getting to their destination. They come down as far as they can and are lost."*

Although the article did not identify the species, this observation is consistent with the subyearling migrant pattern in chinook salmon. It should be noted this problem was identified in 1904.

John Day River

Abundance. As early as 1888, the Oregon State Board of Fish Commissioners (1888b p. 15) remarked that:

> *"The John Day River is quite a large stream, and in former years a large number of salmon ascended it, but within the last few years considerable mining has been done on its head waters, and this keeps the river muddy and the salmon have left it."* (underlining added)

Various interviews with local residents suggest that chinook salmon were more abundant in the 1920s than at present (personal communication; Errol Claire, ODFW, February 14, 1994). A recent report by the Oregon Water Resource Department (1986) estimated historic chinook salmon abundance in the John Day

Basin at 6,000 fish annually. However, the report did not specify the time period. Van Cleve and Ting (1960) also report interviews with local residents that suggested the John Day River supported larger runs in the 1930s than in the 1950s.

Habitat. Habitat loss in the John Day River prior to 1940 was extensive and resulted from mining, irrigation, grazing and timber harvest as in other basins in the region. Early agricultural practices were destructive of stream riparian habitats. Oliver (1967 p. 7-9) described land clearing on his father's ranch in the John Day Basin in the 1880s:

> *"One of the first jobs on the Clark homestead was to clear off the brush and trees. Big cottonwoods grew all along the river and the meadows were covered by wild thorn bushes, to be chopped out by hand.*
>
> *Father took out the big bends, straightened the channel, rip rapped the banks and made each meadow safe. He dried up the wet places. For draining, he dug by hand ditches about two feet deep and 18 inches wide."*

Based on a contemporary understanding of the importance of riparian areas in the John Day Basin, the practices described above probably reduced salmonid standing stocks in the affected reaches (Tait et al. *in press;* Li et al. *in press).*

Loss of riparian areas and wetlands reduces the stability of a stream and increases the incidence of flashy flows and downcutting of the stream channel. In a study of a severely downcut stream in the John Day Basin in Meyers Canyon, a tributary to Bridge Creek, researchers estimated that the incision took place around 1920 and attributed it to Euroamerican perturbation in the watershed (personal communication; Dr. Robert Beschta, Oregon State University, February 11, 1994).

Changes in the Middle Fork of the John Day River between 1881 and the present were evaluated based on the general land survey of 1881 and a 1912 map of the Whitman National Forest (Welcher 1993). Since 1881, the width of the Middle Fork has increased 26 feet, and the active channel which meandered across the valley floor has been constrained to the southern valley wall. The forest map of 1912 shows multiple channels as well as cross valley meandering. Age of trees currently in the riparian zone suggests that the last time the middle fork was allowed to migrate across the valley floor was between 1903 and 1923. This coincides with the construction of a railroad grade (Welcher 1993).

Natural low summer flows, in the John Day River, were reduced further by irrigation diversions (Van Cleve and Ting 1960). A direct effect of irrigation was the use of gravel dams to divert water from the. river. The dams were rebuilt every year in May and some were impassible to migrating adults. A diversion dam built around 1910 near the town of Spray blocked the migration of coho salmon for several years. The dam was washed out in 1934, but not before it eliminated the fall migrating salmon (Neal et al. 1993).

Gold was discovered in the John Day Basin in 1862. The search for gold buried in the gravels of the John Day River degraded major portions of the river's salmon habitat some of which have not recovered to this day. Mining operations silted over spawning gravels and diverted water out of the channel; and gold dredges removed gravel from the riverbed. Gold dredges operated in the John Day Basin until the late 1940's (Leethem 1979).

_ife History. No information on life histories of chinook salmon prior to 1940 was found.

Deschutes River

Abundance. Early explorers reported that salmon were abundant in the Metolius River. Based on the amount of spawning gravel, full seeding of the Metolius River would have required 21,000 chinook salmon (Davidson 1953 cited in Nehlsen 1993).

Crooked River is a tributary to the Upper Deschutes River, which was subjected to early habitat degradation (see discussion below). Spring chinook that migrated to the Crooked River were extirpated by the early 1900s (Nehlsen 1993).

Habitat. There is little information on the historic condition of habitat in the Deschutes Basin. As in other watersheds located in the Cascade rainshadow, large scale irrigation was initiated in the later decades of the 19th Century. The first water for irrigation was diverted in 1871. The demand for water grew rapidly and by 1914 filings for rights to Deschutes River water above the City of Bend exceeded stream flow by 40 times (Nehlsen 1993).

Grazing also destroyed salmon habitat, and some of the most severe degradation occurred before the turn of the century. The timing of habitat degradation in Camp Creek, a tributary to Crooked River, was documented through an analysis of diaries and notes contained in land surveys (Buckley 1992). Downcutting, loss of riparian cover and desertification of the Price Valley and Camp Creek occurred after 1885 but prior to 1903. The dramatic changes in stream habitat came as a result of an interaction between variable climate and intense grazing by livestock brought into the basin by Euroamericans (Buckley 1992).

Life History. No information on histories of chinook salmon prior to 1940 was found.

Template Synopsis

The following summarizes the salient features of the template:

- Spring/summer chinook salmon were in decline by the turn of the century. The fishery compensated for the declining abundance of spring and summer chinook salmon by increasing the harvest of fall chinook salmon. After 1920, there was a severe decline of all races of chinook salmon.

- The general decline in abundance of spring, summer, and fall chinook salmon after 1920 was triggered by deteriorating ocean productivity and a shift to hot/dry climate which reduced the quality of freshwater habitats. The effect of an extended hot/dry weather pattern on salmon production was aggravated by previous massive habitat degradation.

- Harvest contributed to the decline of spring/summer chinook salmon around 1900, and of all races after 1920. Habitat destruction in the subbasins was severe enough by the late 1800's to account for a significant portion of the decline.

- Irrigation withdrawals, grazing, mining and timber harvest contributed to habitat degradation in the high desert streams of the mid-Columbia Basin. Significant loss of spawning and rearing habitat occurred before 1930.

- The available observations of juvenile life histories, though sparse, support the hypothesis that juvenile chinook salmon migrated/reared through the summer in the mainstems of the Columbia River and in the mid-Columbia Subbasins. Migration peaked in the summer.

- Historic flow patterns in the mainstem Columbia were consistent with extended summer migration of juvenile chinook salmon.

- **Similar to spring chinook salmon in other rivers, the juvenile spring/summer chinook in the mid-Columbia Basins probably migrated to sea as subyearlings and yearlings (ocean and stream types) with subyearling migration the dominant life history pattern.**

PATIENT DESCRIPTION

Abundance

The abundance of chinook salmon in the Columbia Basin continued the decline that started in 1920 (Figure 13 A) and extended it through the 1940s, 1950s and 1960s with slight increases in the 1970s and late 1980s (Figure 22). Recent harvests have reached historic lows. The harvest of chinook salmon in the Columbia River since 1940 has never approached the levels achieved from 1890 to 1920. The construction of Bonneville Dam allowed biologists to count salmon migrating upstream and make separate estimates of the minimum run to the river (catch and escapement) for each race of chinook salmon (Figure 23).

Fall chinook have dominated the run except for the early 1950s when the fall and spring run were about equal (Figure 23). Given a predevelopment estimate of 4.7 to 9.2 million chinook salmon in the annual run to the Columbia River (see page 25), the current total run of spring, summer and fall chinook salmon (river catch plus escapement) into the Columbia River is 8 to 15 percent of the predevelopment abundance. However, estimates of the run into the Columbia River do not include interceptions outside the basin.

Similar to the template description of abundance, the data in Figures 22 and 23 mask a significant shift in resource quality. In the late 1950's, following the development of more nutritious feeds, disease treatments and rearing practices, the survival of artificially propagated salmon increased and the percentage of hatchery origin fish in salmon populations began to increase (Lichatowich and Nicholas *in press).* In recent years, hatchery fish have made up 80% of the salmon returning to the Columbia River (NPPC 1992).

Habitat

Mainstem dams created obvious habitat changes in the mainstem Columbia and Snake rivers. Some dams are located within the migratory path of the juvenile and adult salmon from the study streams and these include one or more of the following: Bonneville (1938),[2] The Dalles (1957), John Day (1967), McNary (1953), Ice Harbor (1961), and Lower Monumental (1967) (Figure 24). In addition, large storage reservoirs in the headwaters of the Columbia Basin do not directly affect salmon migration in the mid-Columbia, but those dams are used to

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[2] Date the dam construction was completed in parentheses

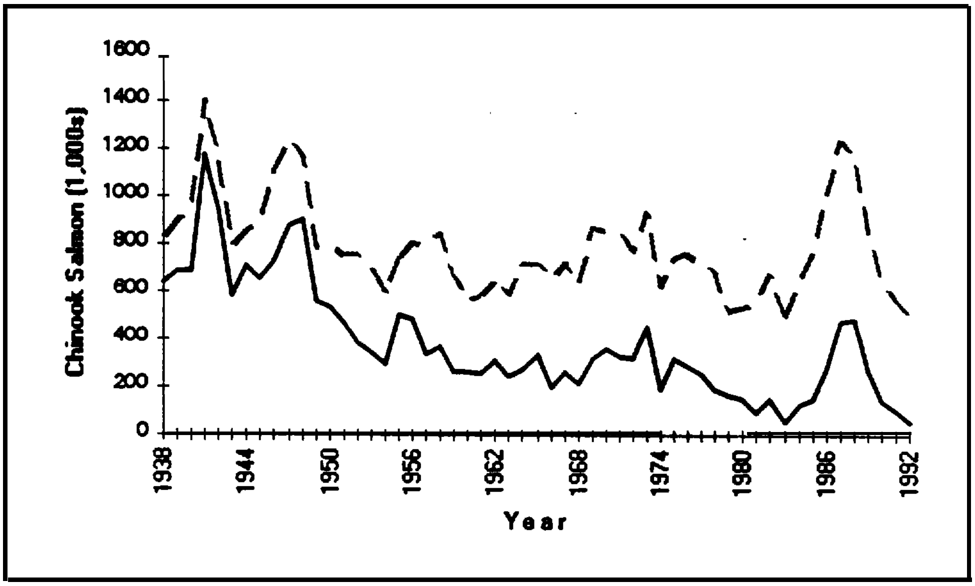


Figure 22. Commercial landings of chinook salmon in the Columbia River (solid line) (1938-1992). Dashed line is the estimated minimum run into the river. (Data from ODFW and WDF 1993).

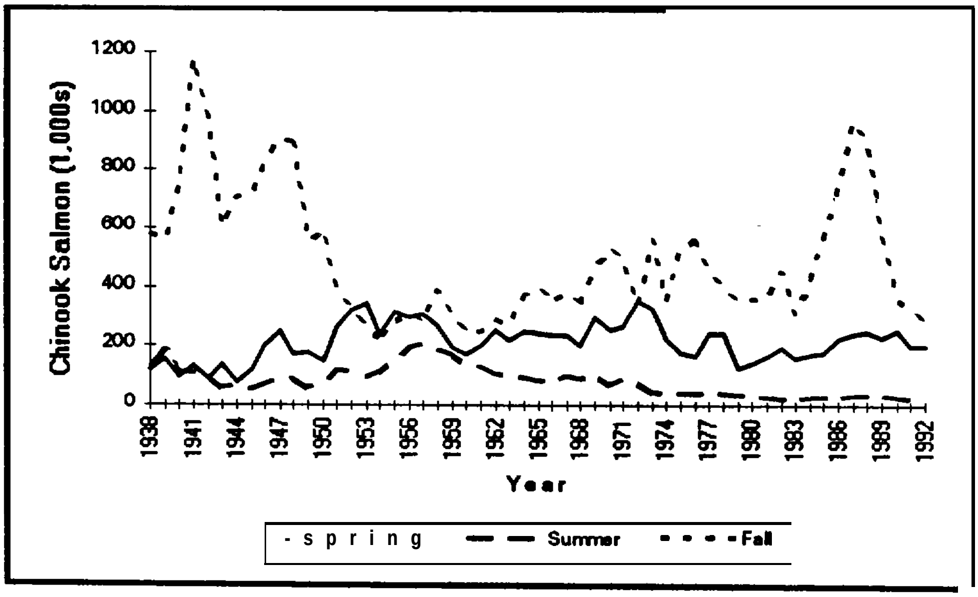


Figure 23. Minimum numbers of spring, summer and fall chinook salmon entering the Columbia River 1938-1992. (Data from ODFW and WDF 1993)

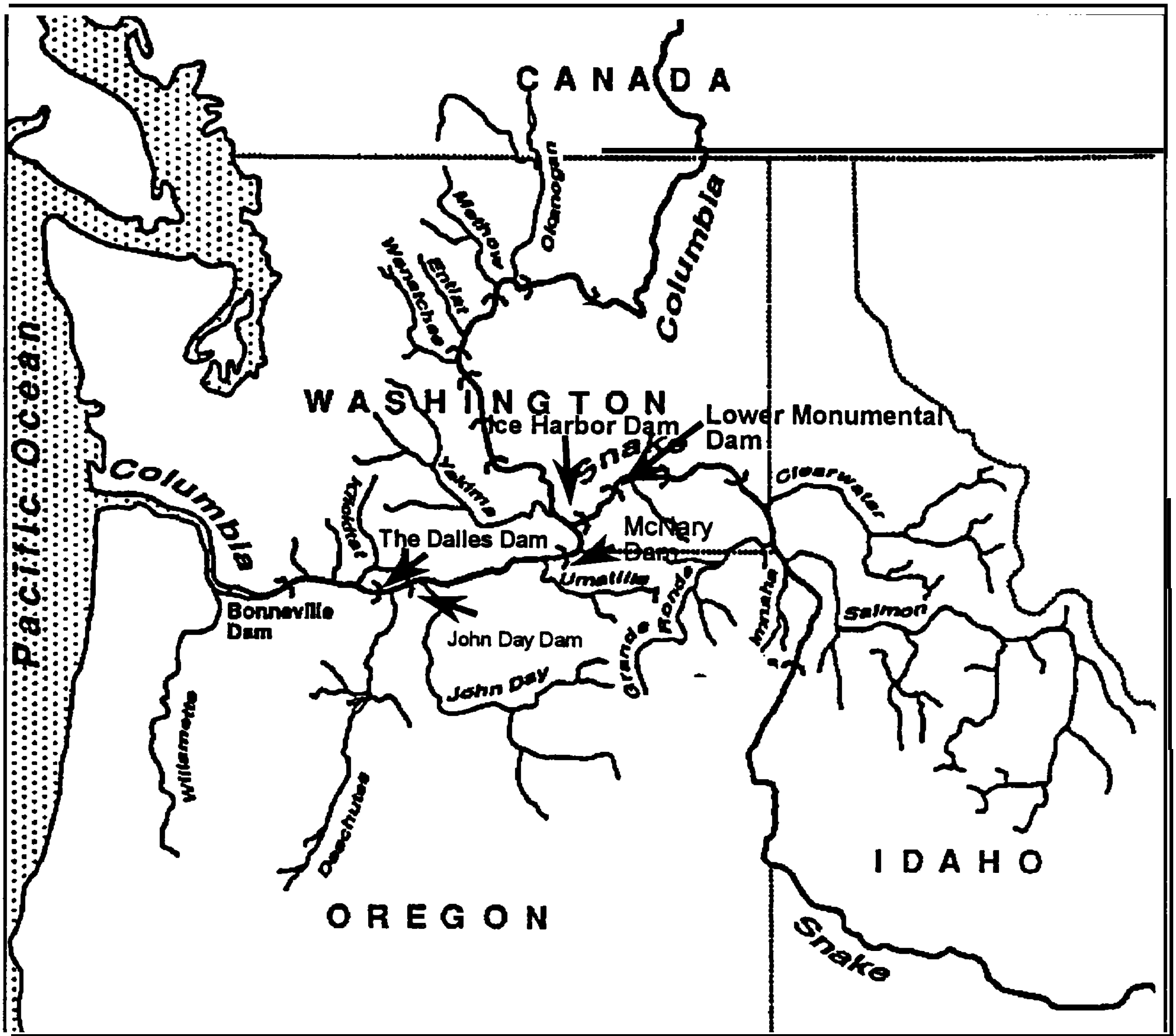


Figure 24. Map showing the location of mainstem dams within the migratory path of juvenile and adult salmon from streams covered in this study. (Taken from Fryer, et al. 1992)

manipulate seasonal flow patterns for power production. The result is a significant change in the natural flow patterns in the mainstem Columbia River (Figures 25 and 26).

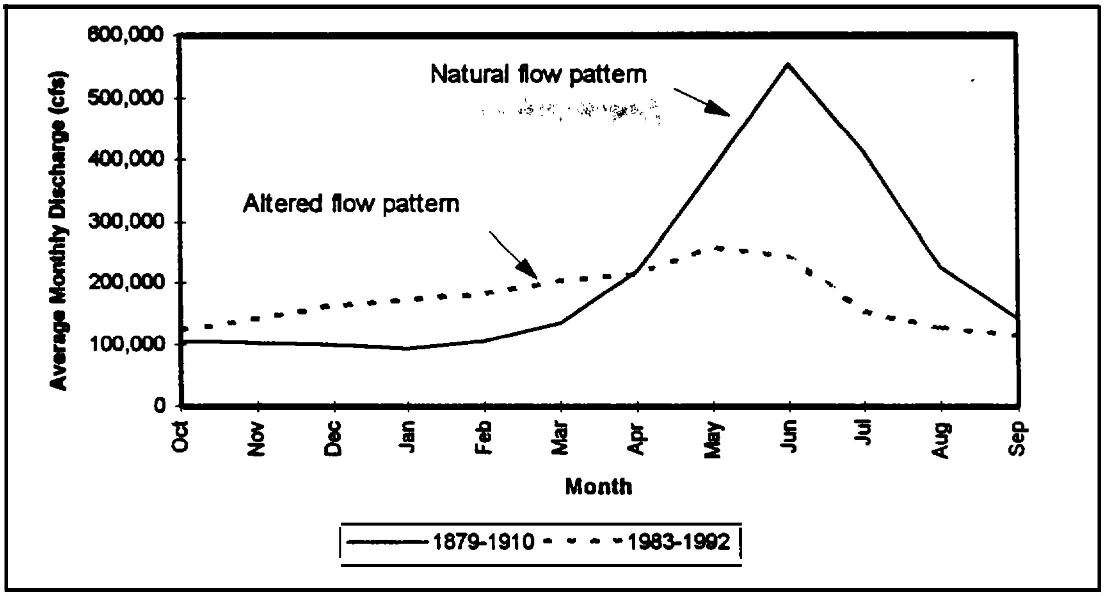


Figure 25. Change in monthly average flows for the periods 1879 to 1910 (natural) and 1983 to 1992 (altered) in the Columbia River at the Dalles, Oregon. (Data from Hydrosphere, Inc. 1990)

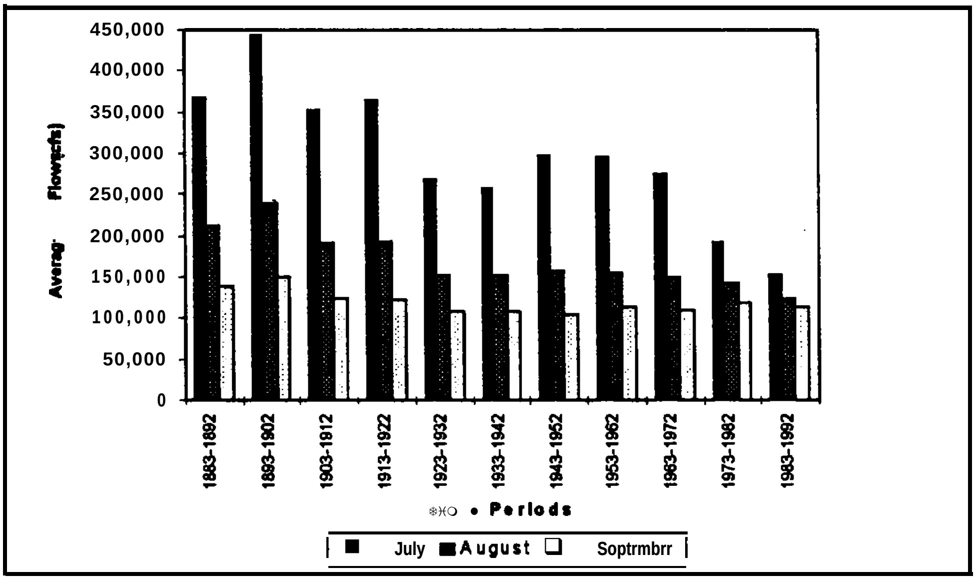


Figure 26. Average flows in the Columbia River at The Dalles for July, August and September for ten year intervals from 1883 to 1992. (Data from Hydrosphere, Inc. 1990)

The construction of storage reservoirs in the basin's headwaters altered the migration habitat of salmon in the mainstem Columbia River. Altered flows and river temperatures could interfere with life histories cued to the normal flow and temperature patterns. A mismatch between life history and an environmental factor such as flow can reduce survival. For example, coho salmon fry from a hatchery stock that exhibited an early time of spawning were planted into several streams in Oregon's coastal basins. Returning adults from the fry plants spawned but survival of their progeny was low. The early spawning adults deposited eggs in the gravel before the normal timing of winter freshets. Eggs subjected to the high flows failed to survive (Nickelson et al. 1986). In Carnation Creek, British Columbia, an increase in temperature following logging advanced smolt migration of coho salmon by less than 2 weeks. Although, the total number of smolts produced increased following logging, the change in smolt migration was followed by a decrease in smolt to adult survival (Holtby 1988).

The effect of altered flow patterns may extend into the estuary and the nearshore oceanic environments. The impoundment of summer flows and their release during the winter (Figure 25) has altered coastal sea surface salinities from California to Alaska (Ebbesmeyer and Tangborn 1993). The change in salinities could be an indication of other changes in coastal ecosystems due to altered flow patterns in the Columbia Basin (Ebbesmeyer and Tangborn 1993).

The mainstem dams and their operation are direct impediments to migration and sources of juvenile and adult mortality. The reservoirs behind the dams have altered the rearing habitat of juvenile salmon and the migratory habitat of juveniles and adults. Ecological changes in the river due to the dams and reservoirs and the introduction of exotic species have increased predation on/or competition with juvenile salmon. Mainstem dams and reservoirs slowed the migration of juvenile chinook salmon (Park 1969; Raymond 1969) which led to a hypothesis that survival is related to the rate of migration and that migration rate is determined by flow (NPPC 1994).

Many of the most egregious land and water development practices that degraded salmon habitat in the subbasins were gradually stopped or improved after 1940. Grazing pressure declined after the climate shifted in the early decades of this century. Gold mining declined and forest management came under better regulations designed to protect stream corridors especially after the 1970s. Irrigation diversions are slowly being screened. Some streams east of the Cascade Mountains have showed continued deterioration in habitat quality while others have improved over the past 50 years (e.g., McIntosh et al. 1994; Smith 1993). However, the development of the region from 1850 to 1940, particularly the appropriation and distribution of water for agriculture left behind a legacy of degraded habitat that time and increasing concern for salmon have not overcome.

Improvements in habitat quality have been observed in some streams since the 1930s (e.g., McIntosh et al. 1994; Smith 1993). However, it is important to remember that current conditions are compared to baseline measurements made in the 1930s. The baselines were established following 50 to 60 years of degradation. Even though some streams have shown improvements in salmon habitats, the quality of the habitat is still less than desired (Smith 1993).

Human economies and ecosystems coevolve (Norgaard 1994) and those coevolutionary processes in the Columbia Basin have established a developmental trajectory for the Columbia ecosystem characterized by diminished capacity for salmon production. The current crisis is the product of the interaction between the existing diminished habitat capacity and a natural low in the productivity cycle. Given the course of development in the Columbia River, each natural trough in productivity in the future will create an extinction crisis for some salmon stocks above Bonneville Dam.

LIFE HISTORY

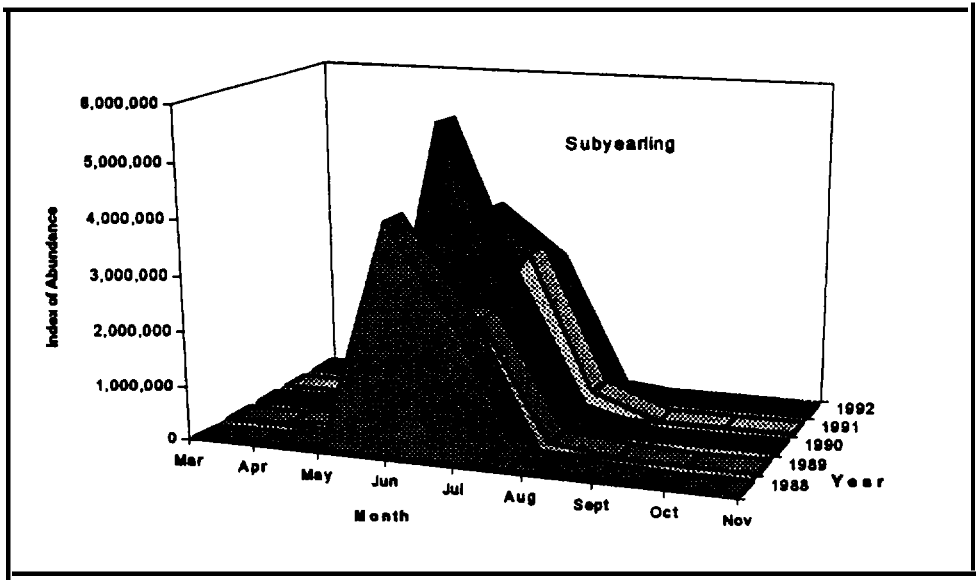
Migration of juvenile chinook salmon in the Columbia River at Byers Landing near the confluence with the Snake River was monitored in 1954 and 1955 (Mains and Smith 1964). The study concluded that the migration of subyearling chinook salmon peaked in March and April. Yearling juveniles migrated later and peaked in June and July. Ages of the migrants were determined by examination of length frequency plots of the seasonal catch.

The use of length frequency to estimate age of juvenile chinook salmon may have introduced error into the analysis. For example, at Priest Rapids Dam the downstream migration of subyearling chinook salmon peaked between July 26 and August 13, and the migration of yearling chinook salmon peaked between May 7 and 23 (Becker 1985). Priest Rapids Dam is upstream from Byers Landing. The sequence of migration peaks for yearling and subyearling chinook salmon at Priest Rapids Dam are the reverse of those reported for Byers Landing (Mains and Smith 1964). The size of the juvenile salmon migrating in March and April (38 mm) (Mains and Smith 1964) was consistent with the expected size of subyearling fish. However, the summer migrants might have been both yearling and subyearling juvenile chinook. In fact, after June, the juvenile chinook salmon identified as yearlings by Mains and Smith (1964) were probably subyearlings. Scales taken from migrating juvenile chinook salmon in 1965 were used to verify the age of fish migrating past Priest Rapids Dam. Nearly all the juvenile chinook salmon collected in July and August were subyearlings (Park 1969).

The migration of juvenile chinook salmon through the mid-Columbia and lower Snake rivers is monitored at mainstem dams (e.g., DeHart 1992). A migration index of yearling and subyearling chinook salmon past McNary and Bonneville dams are shown in Figures 27 and 28 for 1988 through 1992. The yearling migration at Bonneville Dam was 90% complete by May 25, and the subyearling migration was 90% complete by July 8 in 1990.

The migration of juvenile chinook salmon was monitored by beach and purse seine about 100 miles below Bonneville Dam at RM 46. Both yearling and subyearling catch/effort by purse seine peaked in May. Beach seine catch/effort for yearling chinook salmon peaked in April, and for subyearling chinook salmon the catch/effort peaked in July (Figure 29) (Dawley et al. 1981).

Yearling and subyearling chinook salmon apparently had different vulnerabilities to the two collection methods. The purse seine captures larger juvenile salmon than the beach seine (Johnson and Sims 1973).



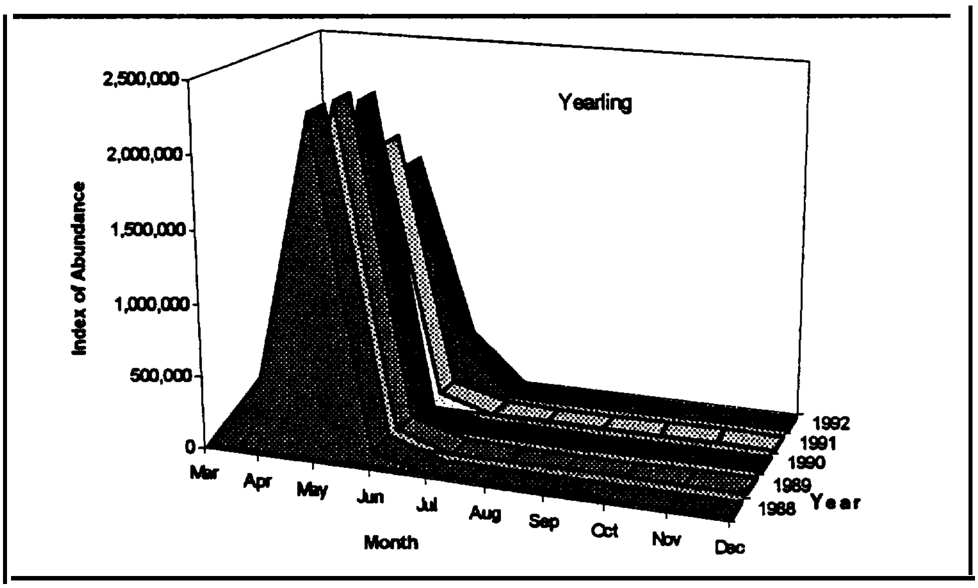
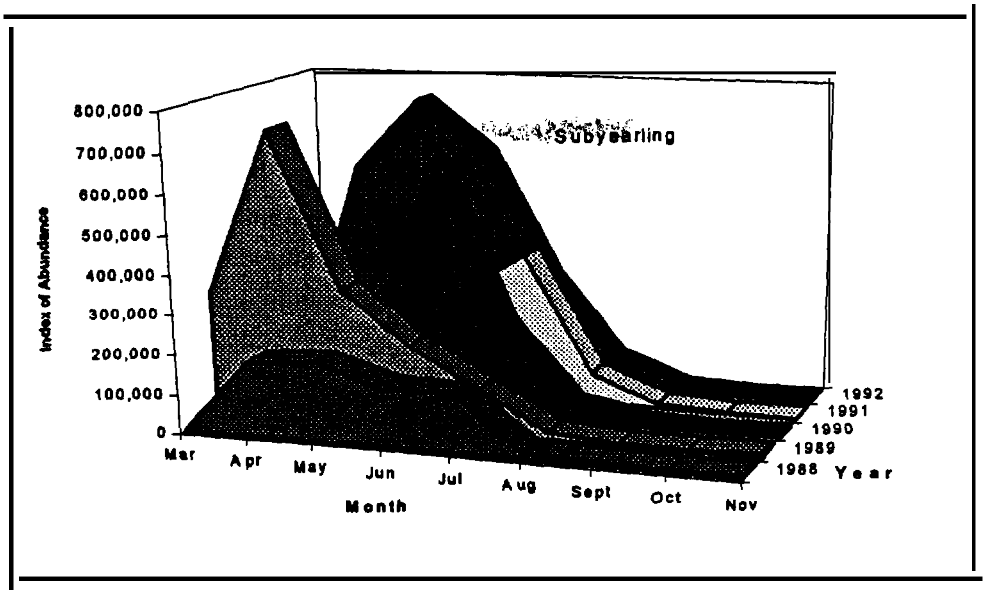


Figure 27. The index of abundance of subyearling and yearling chinook salmon migrating past McNary Dam. (Data from Fish Passage Center, Portland Oregon)



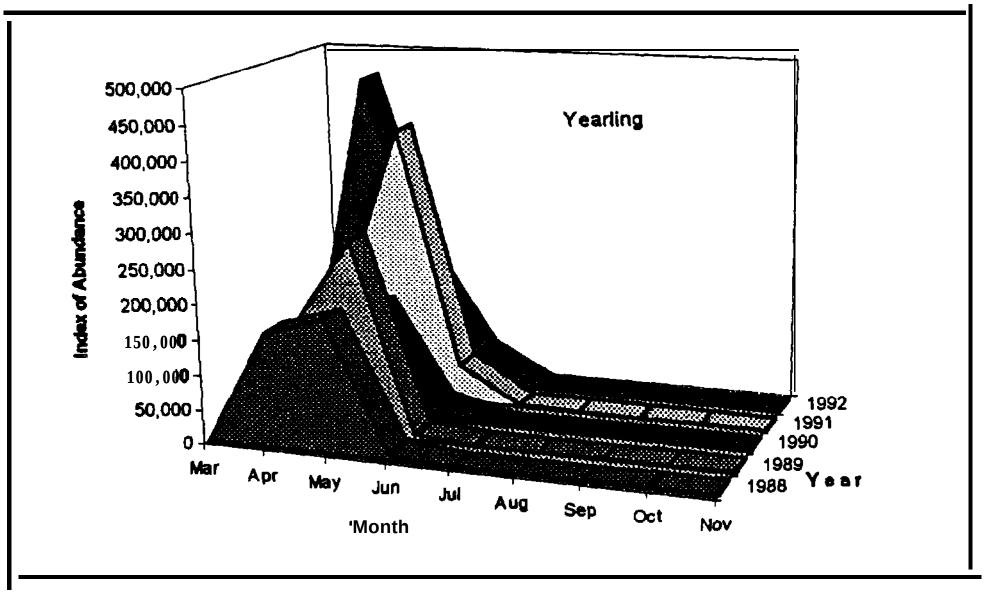
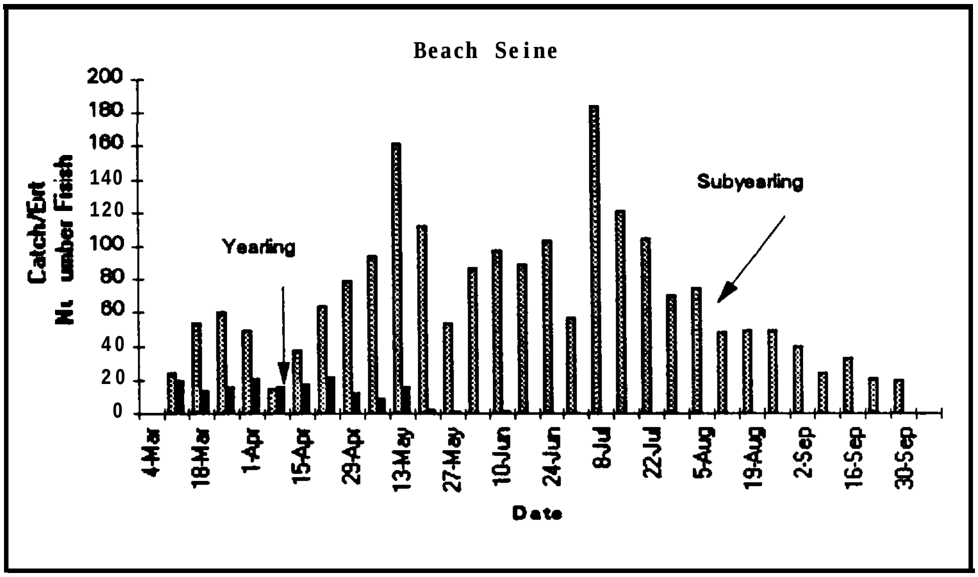


Figure 28. The index of abundance of subyearling and yearling chinook salmon migrating past Bonneville Dam. (Data from Fish Passage Center, Portland, Oregon)



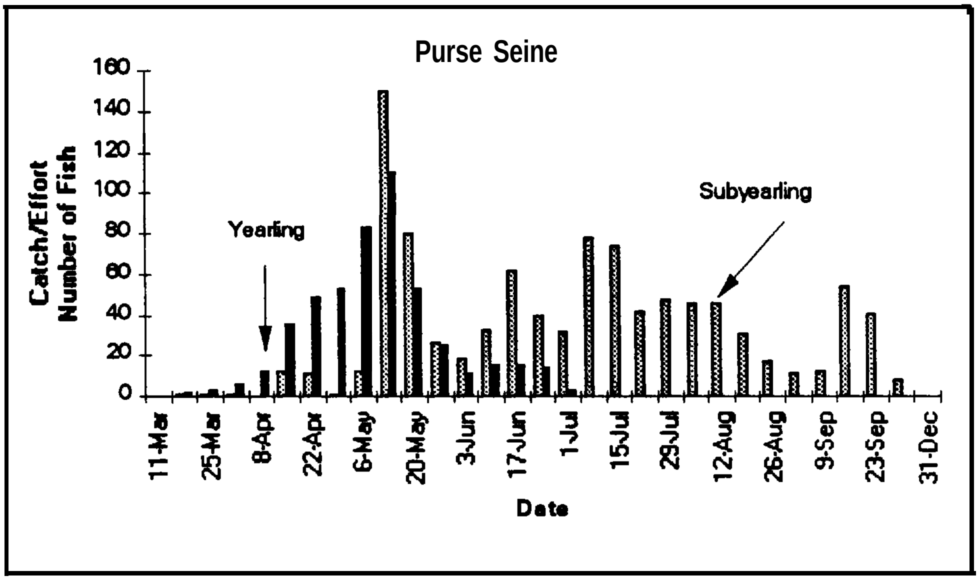


Figure 29. **Yearling and subyearling chinook salmon catch/effort of purse or beach seine at RM 46 in the Columbia River 1980. (From Dawley et al. 1981)**

The age at maturity and juvenile life histories of spring chinook salmon was determined from scales sampled from fish collected at Bonneville Dam in 1987 through 1991 (Figure 30). Age four adults dominated the returning population. Nearly all the spring chinook salmon migrated to sea as yearlings (stream type) (Fryer et al. 1992).

Mid-Columbia Subbasins

Yakima River

Abundance. Since 1957, the return of adult spring chinook to the Yakima River has ranged from a low of 854 fish in 1972 to 12,665 in 1957 (Figure 31). Summer chinook from the Yakima River are extinct (CBFWA 1991). Recent escapements of fall chinook to the Yakima River are estimated at 2,400 natural and hatchery produced fish (CBFWA 1991).

Habitat. Smith (1993) compared stream reaches that were surveyed in 1935-1936 in the Little Naches River and Taneum Creek with identical stream reaches resurveyed in 1990. Pool habitat increased between 1935 and 1990 but is still deficient when compared to west side streams. Spawning habitat and substrate quality decreased between the two surveys (Smith 1993).

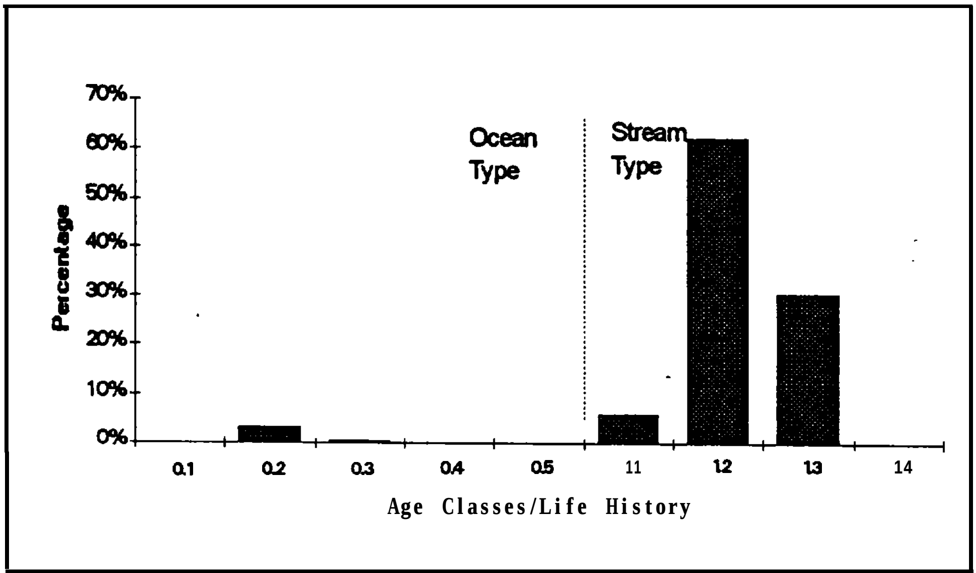


Figure 30. Juvenile life histories and average age of adult spring chinook salmon sampled at Bonneville Dam 1987 to 1990. (Data from Fryer et al. 1992)

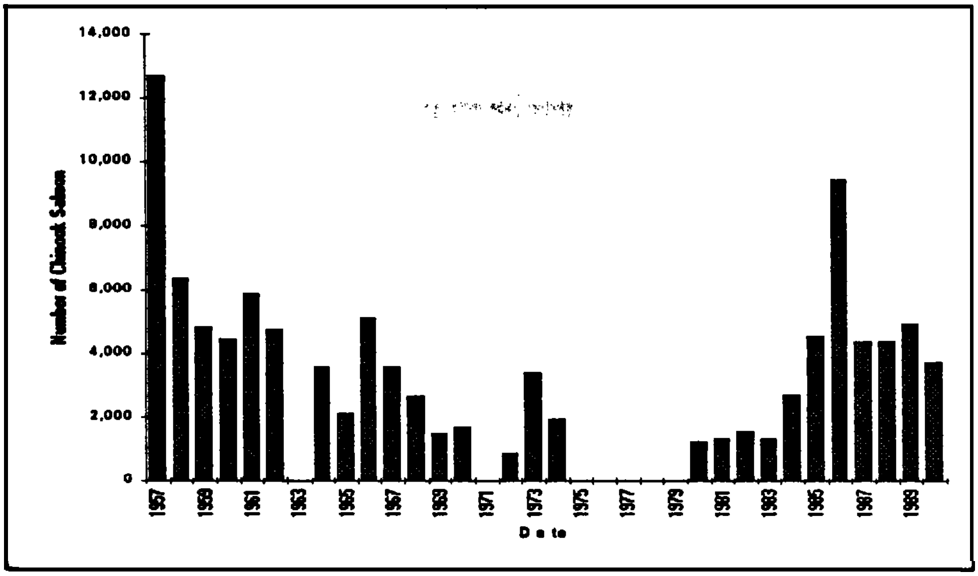


Figure 31. Estimated run of spring chinook salmon to the Yakima River 1951 to 1990. Total run not estimated in 1963, 1971, 1975 to 1979. (Data from Fast et al. 1991)

Smith (1993) concluded that the structure of salmonid habitat had been significantly degraded prior to 1935 due to cumulative impacts of past grazing, recreational use of the river and timber harvest. Salmon habitat in the surveyed reaches showed evidence of a cycle of decline and recovery. Prior to 1935, grazing and pasture burning which caused extensive forest fires degraded salmon habitat. After 1935, salmon habitat showed signs of recovery until the 1960s, followed by a new cycle of decline as timber harvest intensified. The post 1935 cycle of recovery and degradation was determined from an analysis of aerial photographs (Smith 1993).

In addition to the structural features of salmon habitat analyzed by Smith (1993), water use in the basin is also a major constraint on salmon production in the Yakima Basin. Diversion dams with inadequate bypasses for parr and smolts and as many as 67 small to medium diversions still have inadequate, obsolete or deteriorating screening. Water diversions have created excessive temperatures in the lower reaches of the Yakima River. Temperatures below Sunnyside Dam (Figure 19) frequently exceed 75°F and sometimes reach 80°F in July and August. In addition to reduced flows and excessive temperatures in the lower river, low flows in the winter and higher than normal flows in the summer in the canyon area are also detrimental to chinook salmon production (CTYIN et al. 1990).

In a study of the effect of different water management scenarios on the stream temperatures in the Yakima River, the water management scenario that was most effective at reducing temperature used 1981 reservoir releases with no diversions and no return flows, i.e., 1981 reservoir operation but no irrigation diversions (Vaccaro 1986). However, even with that scenario, there was little improvement in the summer water temperatures in the lower river. A return to natural stream flows was least effective in reducing temperature (Vaccaro 1986). However, all the scenarios were evaluated under the current stream channel configuration and riparian cover. Natural flow patterns in a predevelopment stream channel bordered by healthy riparian vegetation would have resulted in lower stream temperatures.

Life History. The principal spawning areas for spring chinook are the Yakima River above Ellensburg and the upper Naches and American rivers. Adults enter the river and begin passing Prosser Dam RM 47.1 in April. The earliest arrival date is April 11 and median passage at Prosser is between May 12 and May 28 (Fast et al. 1991).

Emergence begins in March and continues through mid-June. Juvenile rearing areas fluctuate seasonally and extend further downstream than the spawning distribution. The extent of the downstream rearing distribution varies from year to year depending on temperature. Juvenile spring chinook undertake at least two in basin migrations prior to the smolt outmigration. Fry redistribute themselves downstream from the spawning areas in the upper Yakima River soon after emergence. This migration may extend downstream as far as Prosser, however, most fry remain above the confluence with the Naches River. Few juveniles are found below the Naches during the summer. Juvenile chinook salmon reach their highest concentration in the canyon (RM 129-146) (CTYIN et al. 1990). Fry emerging in the American River redistribute to the middle Naches River to rear, and fry emerging in the upper Naches move to the lower river or into the Yakima River near its confluence with the Naches. Some juvenile spring chinook begin a second migration in late October as temperatures decline. Those juveniles move below Prosser to overwinter (CTYIN et al. 1990).

The outmigration of smolts takes place from March through late June. Until recently it was believed that all Yakima River spring chinook migrated to sea as yearlings. However, recent electrophoric analysis of juvenile chinook salmon migrating in July showed that 40% of the fish over 90 mm were spring chinook (Busack et al. 1991). Those fish may have been yearlings migrating very late or larger subyearlings. Unfortunately no scales were taken to verify age. Juvenile spring chinook have shown a propensity to migrate as subyearlings in the summer in years when flows and temperatures are favorable (personal communication; Bruce Watson, YIN).

Fall chinook salmon spawn in the lower mainstem of the Yakima River. Fisheries managers estimate that 30% of the fall chinook spawn above Prosser. Fall chinook also spawn in Marian Drain which is an irrigation return for the Wapato

Project. The fall chinook spawning migration begins in mid-October and is complete by the third week in November (CTYIN et al. 1990).

Emergence of fall chinook fry peaks in late February. They begin moving past Prosser Dam by late April or early May. Since 1983, the migration of fall chinook smolts at Prosser Dam has been 95% complete between June 17 and July 8 (CTYIN et al. 1990). In 1989, WDF operated a scoop trap below Prosser Dam at RM 7. The catch of juvenile chinook salmon peaked on June 9. Instream mortality of marked release groups of hatchery produced fall chinook was high, ranging from 49% to 90%. Similar trapping in 1992 revealed that low flows periodically caused lethal conditions (high temperatures) for juvenile chinook salmon in the lower Yakima River and heavy predation by small mouth bass, catfish and gulls. In 1992, the outmigration of juvenile chinook salmon was complete by June 20 (personal communication in the form of draft manuscripts; Bruce Watson, YIN).

Patient life history patterns of spring chinook described by Watson (personal communication; Bruce Watson, YIN, 1992) show two life histories which were present in the template period that are now absent (Table 3). The ocean type life history pattern is no longer present. Spring chinook with a stream type life history, specifically those that utilized the lower river tributaries are also no longer present.

Table 3. Description of patient life history patterns in Yakima River spring chinook salmon. (personal communication; Bruce Watson, YIN, 1992)

No.	Spawning Location	Summer Rearing Location (fry to parr)	Winter Rearing Location (pre-smolts)	Smolt Migration Route (subbasin)	Smolt Age
I	Upper tributaries	Upper tributaries	Upper tributaries	Entire drainage	I+
II	Upper tributaries	Upper mainstem	Upper mainstem	~90% of drainage	I+
III	Upper mainstem	Upper mainstem	Upper mainstem	~90% of drainage	I+
V	All drainage units above lower mainstem	All drainage units above lower mainstem	Lower mainstem & associated "sloughs"	<50% of drainage	I+

Tucanno River

Abundance. Escapement of spring chinook salmon to the Tucannon River has averaged 210 fish since 1971. Fall chinook spawning is limited to the lower river below Sarbuck Dam. Between 1976 and 1980, the number of fall chinook salmon redds ranged from 20 to 200. After 1985, standardized surveys were initiated. No redds were observed in 1985 and 1986. In 1987, 1988, 1989 redd counts were 16, 26 and 59, respectively (WDF et al. 1990).

Habitat. The Tucannon River can be divided into four zones based on habitat quality: the mouth to Pataha Creek (RM 10); Pataha Creek to Marengo (RM 24), Marengo to headwaters; and Pataha Creek (WDF et al. 1990) (Figure 32). Habitat deteriorates in a downstream gradient. The lowest reach up to Pataha Creek contains the poorest physical habitat for salmon due to elevated temperatures, heavy sedimentation, irrigation diversion, and degraded riparian zone. The area from Pataha Creek to Marengo also experiences summer stream temperatures at or above the lethal limits for salmonids and experiences the other problems identified in the lowest reach. Habitat conditions improve near Cummings Creek (RM 35) and continue to improve upstream from that point. Salmon production in Pataha Creek is primarily limited by high sedimentation, high road density and chemical pollution associated with agriculture (WDF et al. 1990).

_ife History. Spring chinook begin spawning in late August. Spawning peaks in the first or second week in September and is completed by the end of September. Spring chinook fry generally emerge in February. Migration of juvenile chinook salmon was monitored in the mid-1950s with Fyke nets at the mouth of the river and at RM 18 (Mains and Smith 1955 cited in WDF et al. 1990). The pattern of juvenile migration showed peaks in November, April and May. The majority of the juveniles were trapped in April and May. In recent years, a migration of yearlings peaked between April 26 and May 10. The mean length of the migrants was 89 mm (WDF et al. 1990).

Umatilla River

Abundance. A program to reintroduce spring and fall chinook and coho salmon and enhance steelhead in the Umatilla River was recently initiated. Prior to the restoration program, steelhead escapement to the river averaged 2,091 adults (1966-1 987). Hatchery releases have produced recent spring chinook returns ranging from 13 to 1,291 fish between 1988 and 1991. Fall chinook returns from hatchery plants ranged from 61 to 468 adult fish between 1985-l 991 (Lichatowich 1992).

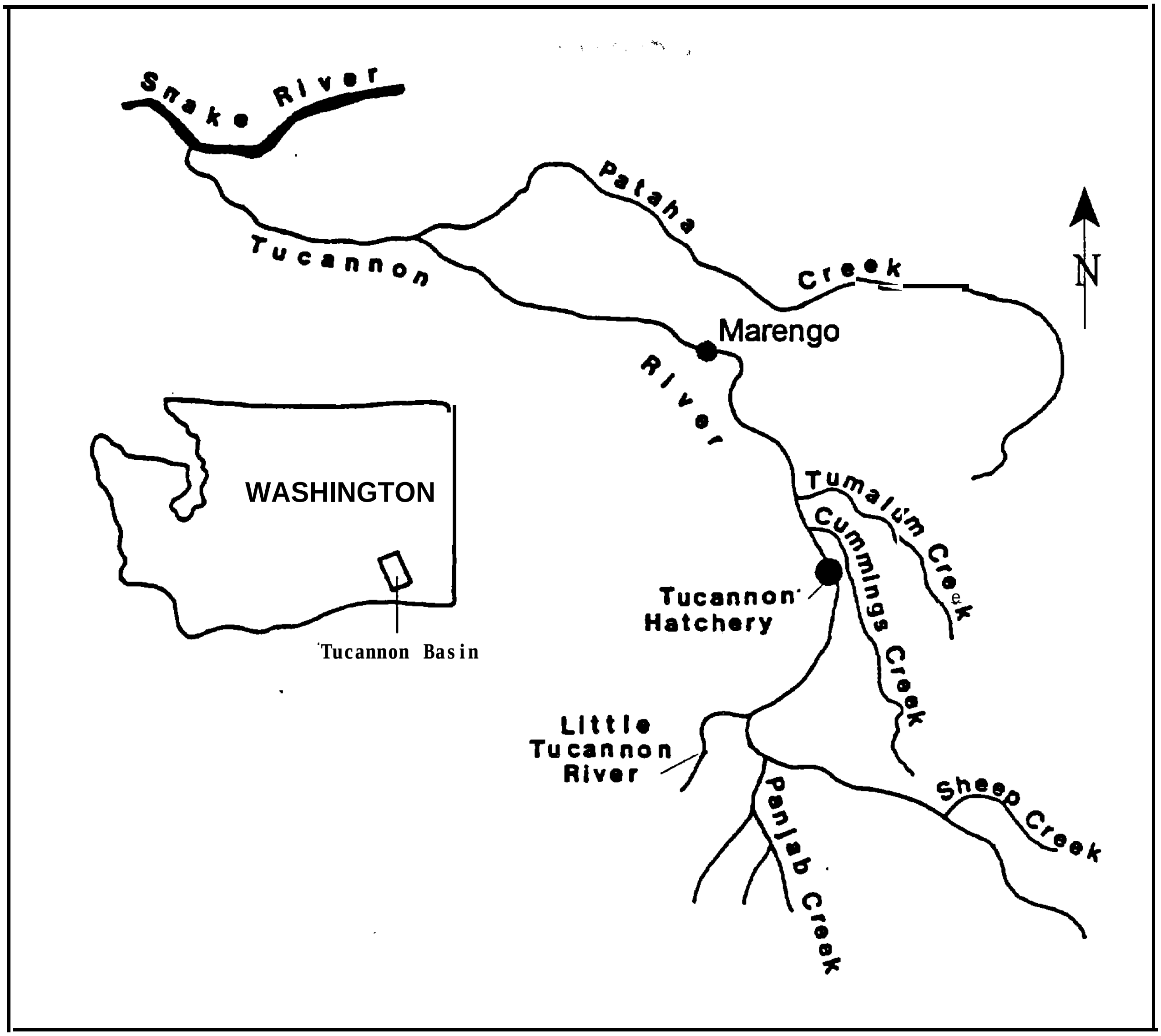


Figure 32. Tucannon River showing locations mentioned in the text. (From Bugert et al. 1991)

Habitat. The Umatilla River restoration program includes major investments in water management to provide partial restoration of lower river flows for fish passage. Irrigation is the principal water use that conflicts with salmon production and habitat quality. The basin has nearly 4,000 water rights on record for a total of 4,600 cubic feet per second. This level of water withdrawal has rendered the lower 32 miles of the Umatilla River unsuitable for summer and early fall rearing of salmonids. In low flow years, problems may develop early enough to impede the spring outmigration of juveniles and upstream migration of spring chinook adults (CTUIR and ODFW 1990).

Riparian zones are generally healthy in the higher elevations, however livestock grazing, road building and timber harvest have degraded mid-elevation riparian zones, and in the lower elevations riparian zones are in poor condition (CTUIR and ODFW 1990).

Life History. Studies of the life history of reintroduced chinook salmon in the Umatilla Basin have recently been initiated.

John Day River

Abundance. Escapement of spring chinook salmon into the John Day River ranged from 918 to 1,923 fish between 1978 and 1985 (Lindsay et al. 1986). Fall chinook escapement into the John Day River is estimated at 100 fish (Olsen et al. 1992).

Habitat. The summer rearing distribution of spring chinook in the north and middle forks of the John Day River appears to be limited by temperature (Figure 33). Juvenile chinook salmon were not found below thermograph stations that had reached a temperature of $20^{0}C$ ($68^{0}F$) (Lindsay et al. 1986). After emergence, juvenile spring chinook moved downstream, usually from May through July. As flows decreased and temperatures increased the juveniles moved back upstream (Figure 33). The largest constriction of habitat occurs in August, although, in some years the constriction could occur as early as July. By October, when temperatures cooled, the juveniles moved downstream again (Lindsay et al. 1986). The John Day River supports extensive irrigation (Oregon Water Resources Department 1986) which contributes to low summer flows and temperature problems.

The resurgence of gold mining following an increase in the government controlled price of gold (Leethem 1979) devastated salmon habitat in the 1930s and 1940s (Neal et al. 1993). The introduction of exotic predators (small mouth bass and channel catfish) have also altered the biological habitat for juvenile chinook salmon. Grazing in the riparian zones of the John Day River have contributed to elevated temperatures, bank erosion, siltation and intermittent flows (Li et al. *in*

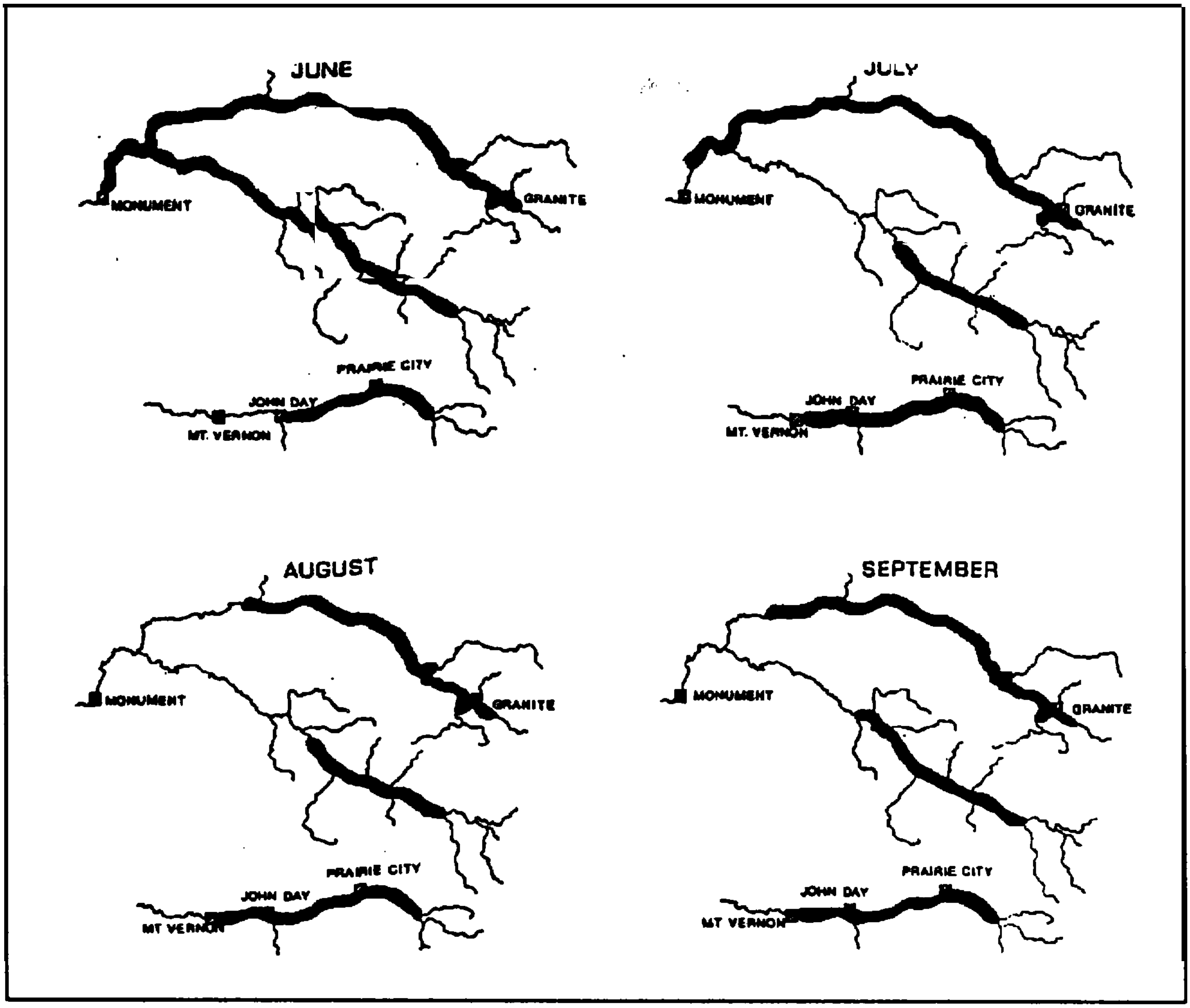


Figure 33. **Shifting rearing distributions of O-Age spring chinook salmon June-September 1981 in the John Day Basin. (Lindsay et al. 1981)**

press). The loss of riparian cover has a greater negative impact on salmonids in desert streams such as those in this study, than in streams west of the Cascade Mountain Range (Li et al. *in press).*

Life History. Spring chinook spawning in the John Day River takes place from late August through September. Examination of coded wire tags recovered on spawning grounds show a high degree of adult homing fidelity. Adult fish returned to spawn in the same areas where they were captured and tagged as juveniles (Lindsay et al. 1986).

Juvenile spring chinook salmon emerged from the gravel in February and March in the mainstem John Day River and in April in the North Fork. Smolt migration out of the upper rearing areas of the North and Middle forks and the mainstem took place from February through May. Smolt migration lower in the river at Spray took place from mid-February to mid-June with a peak during the first two weeks in April. Nearly all juveniles migrate to sea as yearlings (Lindsay et al. 1986). The summer movement of juvenile spring chinook salmon in the John Day River (Figure 331, suggests that cooler river temperatures through the lower mainstem could produce an ocean type life history.

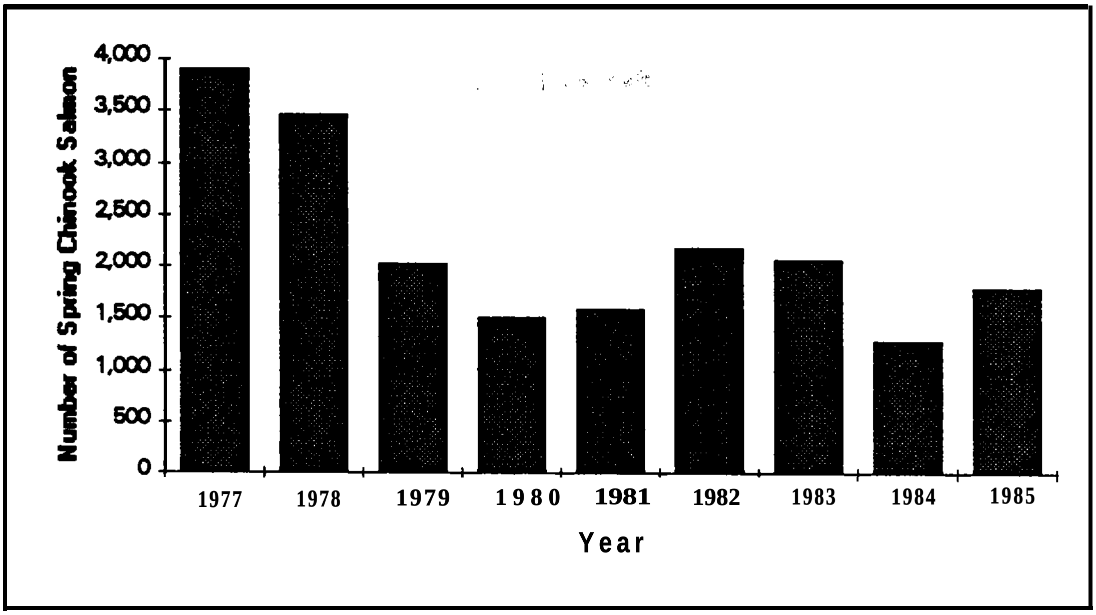
Deschutes River

Abundance. In river catch and escapement of spring chinook in the Deschutes River (1977-l 985) ranged form 3,895 to 1,290 fish. Catch and escapement of wild fall chinook (1977-l 988) ranged from 5,219 to 11,772 fish (Figure 34) (ODFW and CTWSR 1990).

Habitat. Unlike the other subbasins discussed thus far, the lower Deschutes River is not plagued with excessive temperatures. However, the only remaining spawning areas for spring chinook salmon is in the two tributaries, the Warm Springs River and Shittike Creek. Those streams do experience elevated temperature in their lower reaches in summer (ODFW and CTWSR 1990).

The Pelton-Round Butte Hydroelectric complex eliminated anadromous salmon production in the upper Deschutes River, including tributaries such as the Metolius River. The anadromous runs have been blocked since 1958 at RM 100 by the Pelton Reregulating Dam.

For fall chinook, the major habitat constraints are the quantity and quality of spawning gravel. Sedimentation from glacial silt below the confluence with White River and sedimentation from grazing and recreation have degraded gravel quality while Round Butte and Pelton dams have influenced the quantity of gravel (ODFW and CTWSR 1990).



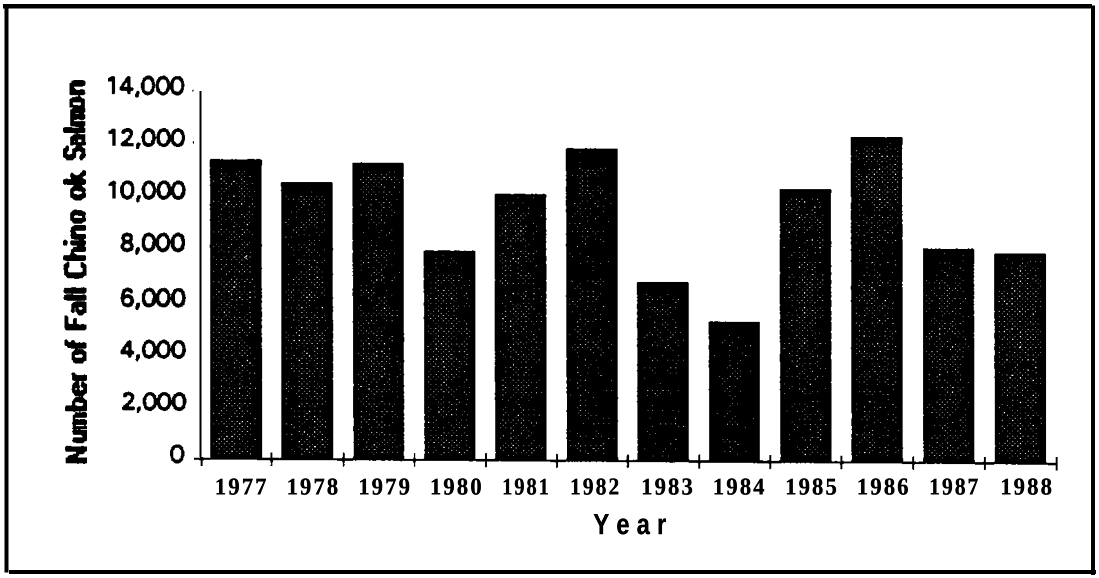


Figure 34. **Total** number of naturally produced spring and fall **chinook adults** returning to the Deschutes River (1977-1988). Annual estimates include harvest, escapement and for spring chinook, brood fish sent to Warm Springs and Round Butte Hatcheries. **(From ODFW and CTWSR 1990).**

Ceratomyxa shasta is a biological factor constraining the production of chinook salmon in the Deschutes River. Juvenile chinook salmon in the mainstem Deschutes probably incur high mortality in July due to the seasonally high infection rate of the parasite. The presence of C. *shasta* and its impact on juvenile chinook salmon might be aggravated by spore production from rainbow trout in Lake Simtustus. Juvenile chinook salmon in the mainstem Deschutes River between May/June and September are subjected to high mortality (Ratliff 1981).

Life history. Most spring chinook spawn in the Warm Springs River; a few also spawn in Shittike Creek. The juveniles emerge in February and March and rear in all major spawning areas. Migration of juvenile spring chinook salmon in the Warm Springs River peaks in fall from September to December and in spring from February through May (Lindsay et al. 1989). Most of the juveniles that migrate from the Warm Springs River in the fall over-winter in the mainstem Deschutes or Columbia rivers then migrate to sea the following spring. About 1% of the juveniles migrate to sea as subyearlings (Lindsay et al. 1989).

Fall chinook spawn throughout the mainstem of the Deschutes River below the Pelton Reregulating Dam. The heaviest concentration of spawners is in the upper six miles of the accessible river. Spawning begins in late September, peaks in November and is completed by December. Scales were sampled from fall chinook returning to the Deschutes River and 96 percent had the ocean type life history (Jonasson and Lindsay 1988).

Juvenile fall chinook emerge from the gravel in February. Emergence was completed by April from the mouth of the Deschutes River to Dry Creek and May for the area from Dry Creek to the Pelton Reregulating Dam. Fall chinook reared in areas and densities that correspond to the density and area of spawning. Peak migration to sea is in the summer of their first year at lengths ranging from 80-92 mm. The larger juveniles migrate downstream first. Migration through the lower river takes place from May to early July (Jonasson and Lindsay 1988).

Patient Synopsis

- The abundance of chinook salmon continued to decline in the 1940s and 1950s followed by another major shift in resource quality as natural production declined and hatchery production increased in importance.

- Habitat continued to degrade in some streams while others showed evidence of improvement.

- Salmon habitat in the Yakima, Tucannon, Umatilla and John Day rivers is fragmented. The lower reaches of those streams are barriers to juvenile migration during summer months due to lethal stream temperatures. The mainstem Deschutes is not subject to a thermal barrier but *C. shasta* may constitute a barrier preventing juvenile chinook salmon from effectively rearing or migrating through the mainstem during the summer months.

- Although there is evidence to suggest that juvenile spring chinook salmon did undertake summer migration (ocean type life history), poor habitat conditions prevent the expression of that life history pattern in all the subbasins.

- Seasonal flow patterns in the mainstem Columbia have shifted dramatically. The current flow patterns probably do not favor extended migration of spring chinook salmon through the summer and early fall months.

- Changes in seasonal flow patterns in the mainstem Columbia River may alter habitat quality in the estuary and nearshore ocean.

- Mainstem dams have increased mortality of juvenile and adult migrants.

DIAGNOSIS

Quantity and Quality of the Resource

Intensification of commercial exploitation of chinook salmon in the Columbia River began in 1866. Since then, the harvest of chinook salmon can be divided into four phases: Initial development of the fishery (1866–1888); a period of sustained harvest with an average annual catch of about 25 million pounds (1889-1922); resource decline with an average annual harvest of 15 million pounds (1923–1958); and maintenance at a depressed level of production of about 5 million pounds (1958 to the present) (Figure 35). Recent declines may indicate the system is slipping to a new, lower level of productivity. Using the same data as shown in Figure 35, Mundy (*in* press) identified five phases in the commercial harvest of chinook salmon in the Columbia River. Mundy's five phases started with the years 1866, 1884, 1921, 1932 and 1953. Our four phases and Mundy's five phases generally agree with the four phases shown in Figure 35, except Mundy divided our phase three (decline) into the years prior to and after construction of the mainstem dams.

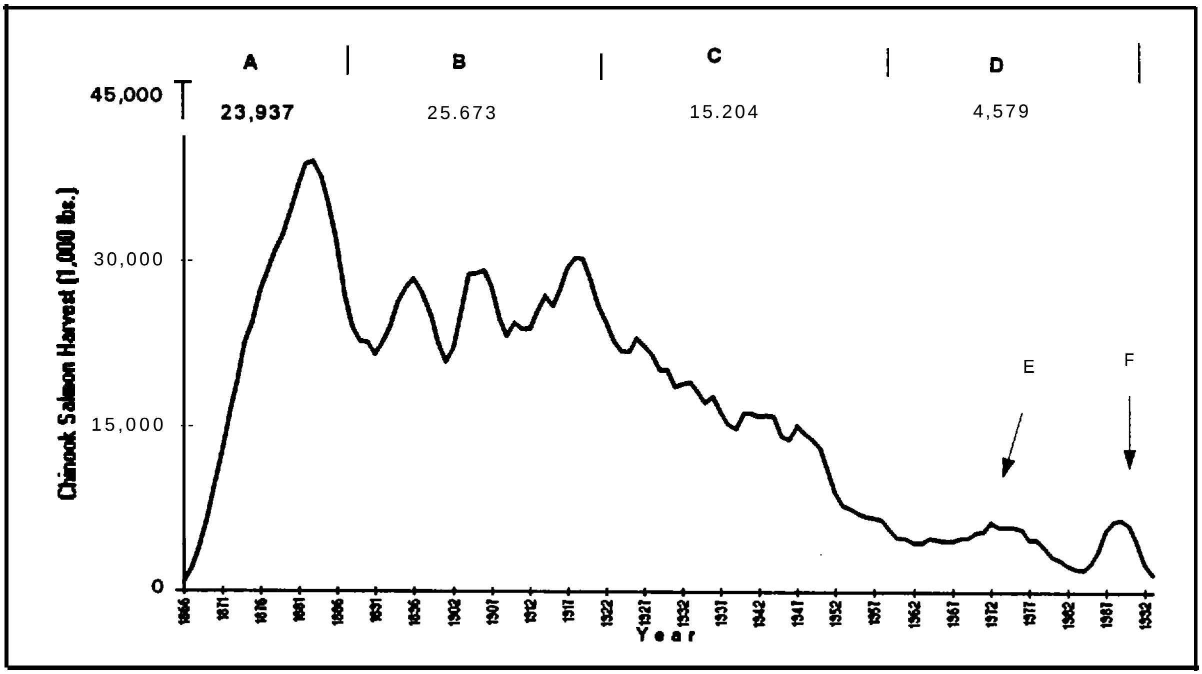


Figure 35. Five year running average of chinook salmon harvest in the Columbia River (1866 to 1992). Time periods A-D explained in the text. Numbers within each period are average harvest. E and F are recent peaks in harvest. (From Beiningen 1976; ODFW and WDF 1993)

The data presented in Figure 35 and the four stages derived from those data are based entirely on measures of resource quantity — the pounds of fish harvested. The pattern of resource quantity shown in Figure 35 masks an important shift in quality that took place between 1890 and 1920. The racial composition of the harvest and apparently the productivity of the individual races of chinook salmon were changing (Figures 14 and 15). Spring and summer chinook salmon declined significantly between 1883 and 1920; and to maintain production, harvest shifted to fall chinook salmon. The decline of the spring/summer races represents a loss of the biodiversity within the chinook salmon of the Columbia Basin. It was suggested, that the decline in spring/summer chinook probably started by 1911 (Craig and Hacker 1940). However, the timing of habitat degradation in the mid-Columbia subbasins suggests that the decline in productivity probably started before the turn of the century.

After the 1960s, increases in the survival of hatchery reared fish created another shift in resource quality. Natural production continued to decline and was numerically replaced with hatchery fish. Salmon of hatchery origin now make up about 80% of the total adult run into the Columbia River (NPPC 1992). Artificial propagation of salmon in the Columbia Basin has not been able to return production to the pre-1920 levels or induce a sustained increasing trend (see Figure 35).

Hatchery programs have traditionally been focused on production numbers (quantity rather than quality).[3] Restoration and management also focus on quantity and ignore resource quality. Between 1890 and the present, there has been a continuing loss of biodiversity, loss of natural productivity and loss of quality in the chinook salmon resource. The strictly numerical approach has not proven effective in the past in the Columbia River or in other regional redevelopment programs (Regier and Baskerville 1986). Restoration objectives should contain targets for resource quality as well as quantity (RASP 1992).

Chinook Salmon Declines in the Subbasins

The Yakima is the only river among those included in this study, for which predevelopment estimates of the abundance of chinook salmon are available (Table 4). In the period roughly corresponding to the early development and sustainable harvest (Phases A and B) in Figure 35, salmon in the Yakima River declined from an estimated annual run of about 500,000 to 20,000 adults. Some of the decline

[3] In-hatchery quality of the juvenile salmon has received attention. Quality as used here refers to ecological quality of hatchery reared fish based on their performance once they are released into the ecosystem.

Table 4. Abundance of chinook salmon in mid-Columbia tributaries in the template (1860-1940) and patient (1941-present) periods. (See text for data sources)

Tributary	Template Abundance		Patient Abundance
Yakima	Prior to 1847	500,000 predominately chinook	854-I 2,665 spring chinook.
	1847-1905	1 oo,ooo-20,000 chinook salmon	Summer chinook, extinct.
	1905-1930	~20,000 chinook salmon	2,400 fall chinook,
	1930-1949	1,000-I ,500 spring chinook	
Tucannon	No estimate		2,400 average and up to 5,000 spring chinook in the 1950s. Recent average 200 spring chinook. 0-59 fall chinook redds.
Umatilla	Large numbers of salmon in river in 1914 from anecdotal evidence.		Native chinook extirpated. Restoration program recently initiated. Natural production not known.
John Day	Large numbers of salmon from anecdotal evidence.		918-1,923 spring chinook escapement. ~100 fall chinook
Deschutes	Large numbers of salmon from anecdotal evidence.		1,290-3895 spring chinook, 5,219-11,772 fall chinook.

represents interception fisheries in the lower Columbia. However, the template discussion suggests early and significant destruction of habitat in the mid-Columbia Subbasins. An important part of the early decline in chinook salmon was certainly a consequence of habitat destruction.

The decline of chinook salmon in the Yakima River is probably consistent with the magnitude and timing of declines in the other streams in this study. In the Umatilla River, large numbers of fish were reported in the river as late as 1914 but the construction of two dams in the lower river extirpated chinook salmon before the 1920s. Anecdotal information suggests much larger runs of chinook salmon in the Deschutes and John Day rivers than today.

Habitat Degradation

The decline of spring/summer chinook early in this century was attributed to overharvest and habitat destruction (Craig and Hacker 19401 with overharvest generally receiving the greater emphasis (Mundy *in* press). However, spring and summer chinook were particularly vulnerable to the kinds of habitat degradation that took place in the last decades of the 19th and early decades of the 20th centuries. Grazing and timber harvest stripped away riparian vegetation and wetlands were drained. In the high desert subbasins, the loss of riparian cover has significant effects on the quality of salmon habitat including structural complexity and temperature (Li et al. *in* press). Water temperatures in the high desert rivers are more sensitive to loss of riparian cover and are more likely to exhibit negative effects on salmonids than streams west of the Cascade Mountains (Li et al. *in press).*

Another important source of habitat degradation was gravity irrigation systems which diverted water from rivers at higher elevations for distribution to farms at lower elevations. Irrigation diversions would have impacted production of spring and summer. chinook salmon to a greater degree than fall chinook salmon. Spring and summer chinook generally spawn in the upper or middle reaches of a river above irrigation diversions whereas the spawning distributions of fall chinook salmon are largely below the diversions (Figures 36-39).

The spawning distribution of spring and summer chinook salmon and the location of irrigation diversions create a major conflict between unscreened diversions and juvenile spring/summer chinook salmon — more specifically, spring/summer chinook salmon with the ocean type life history pattern. Juvenile chinook salmon with the ocean type life history migrate downstream in late spring and summer at the same time that there is high demand for irrigation water. Those fish would have been diverted into irrigation ditches and left to die in large numbers in the

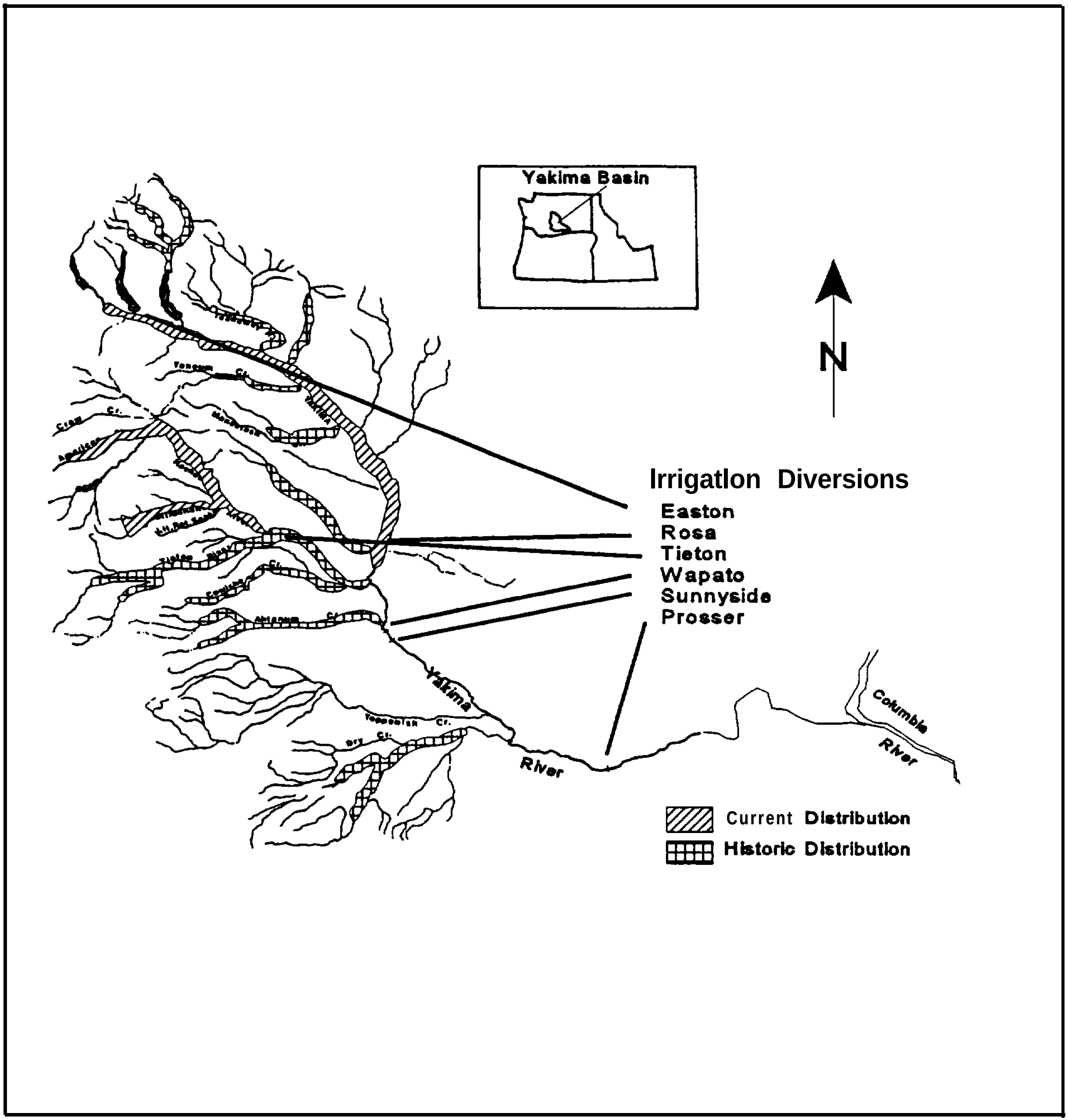


Figure 36. **Location of major irrigation diversions and the current and historic spawning distribution of spring chinook salmon in the Yakima Basin. (Distributions are estimates obtained from CTYIN et al. 1990; personal communication; Bruce Watson, YIN, August 31, 1994)**

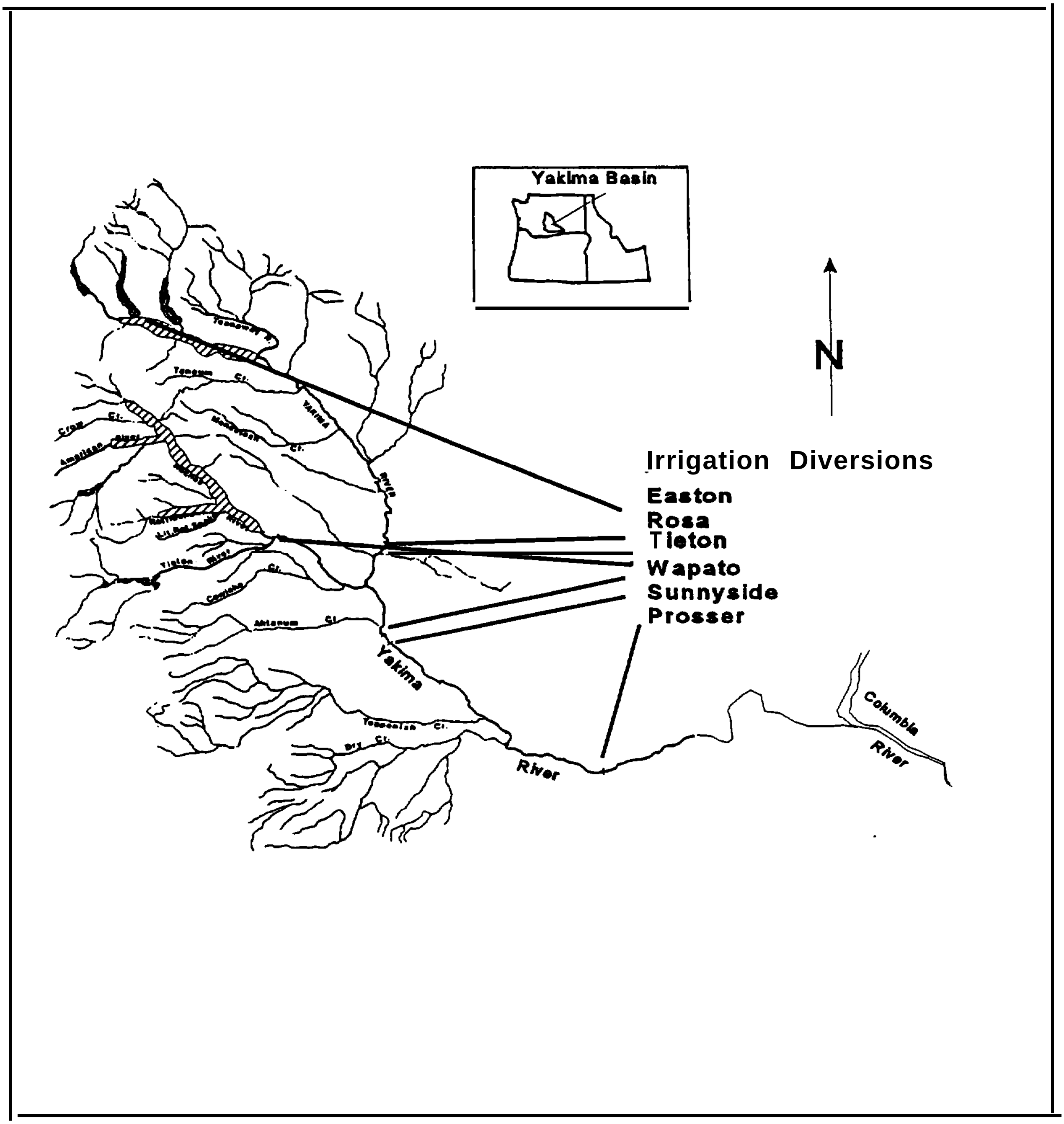


Figure 37. **Areas in the Yakima Basin where 83 percent of the current spring chinook salmon spawning takes place. (personal communication; Bruce Watson, YIN, August 31, 1994)**

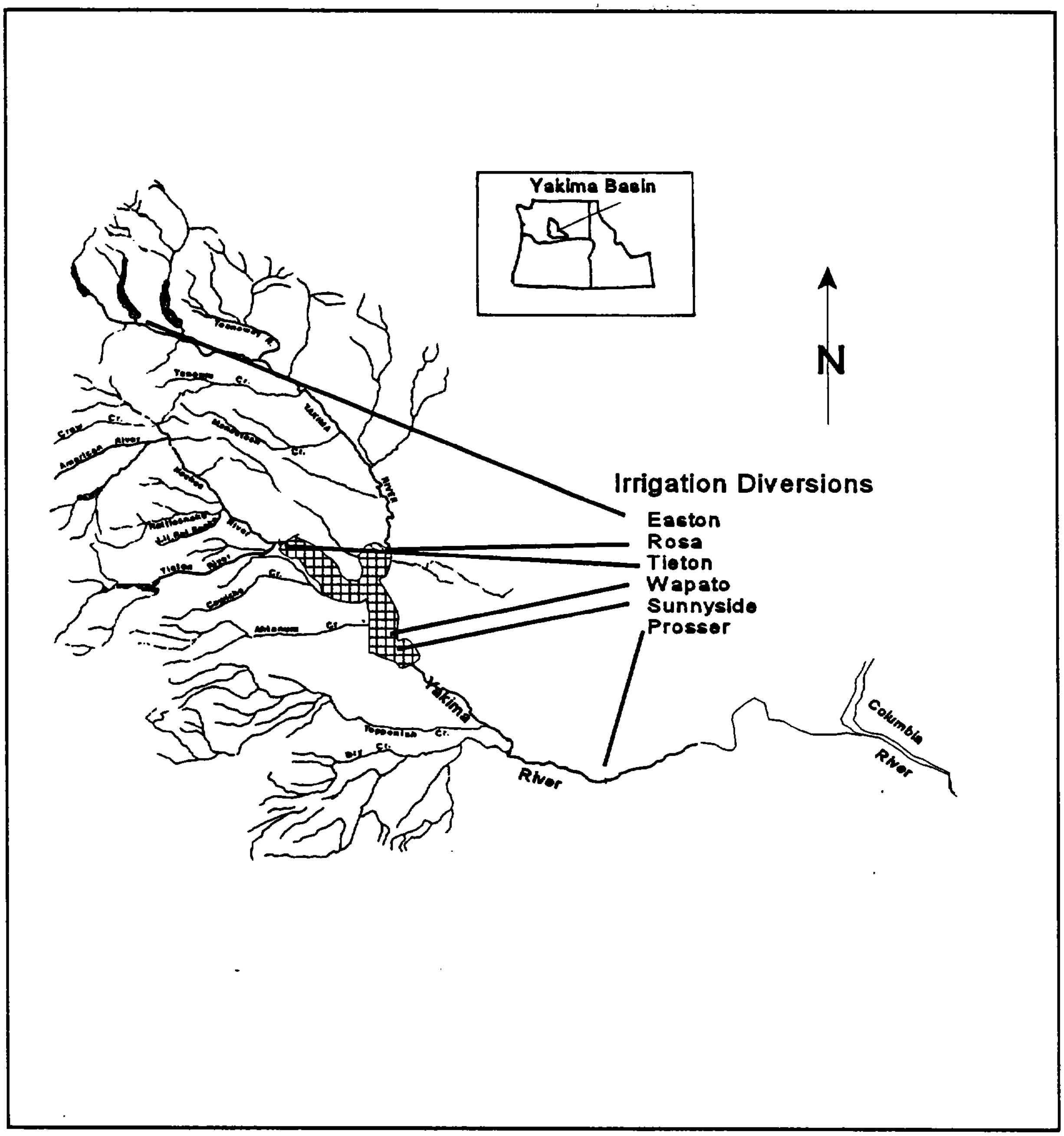


Figure 38. Location of major irrigation diversions and the historic spawning distribution of summer chinook salmon in the Yakima Basin. (From CTYIN et al. 1990)

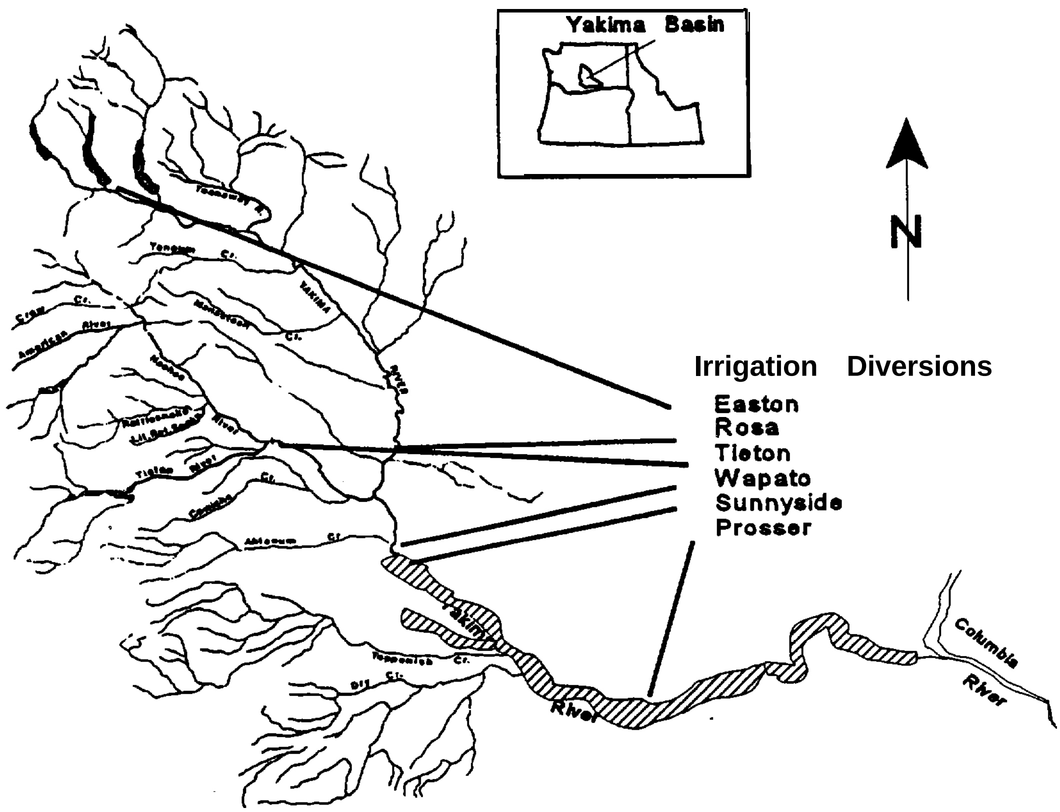


Figure 39. Location of major irrigation diversions and the current spawning distribution of fall chinook salmon in the Yakima Basin. **(personal communication; Bruce Watson, YIN, August 31, 1994)**

watered fields. This in large part explains the hypothesized loss of life history diversity in the Yakima Basin (personal communication; Bruce Watson, YIN, 1992).

Land clearing, overgrazing of riparian vegetation, draining of wetlands, channel straightening and water diversions destroyed habitat connectivity within a basin and between the subbasin and the mainstem. Loss of connectivity fragmented the salmon habitat in the mid-Columbia subbasins (e.g. Figures 36 and 37) and is most evident in the lower reaches of those streams (Table 5). The cumulative effects of development dewatered the lower reaches of tributaries or elevated temperatures beyond the preference or tolerance of salmon. The combination of unscreened irrigation diversions and loss of riparian cover created thermal or physical barriers that would have destroyed the ocean type life history pattern in spring and summer chinook salmon. This assumes that stream temperatures under natural instream flows and healthy riparian cover would have remained within the liveable range for juvenile chinook salmon. The latter is a critical uncertainty discussed later in this report.

There is an interaction between the Intensive harvest and loss of productivity associated with the subyearling life history pattern. The loss of subyearling smolts in irrigation diversions would have significantly reduced the optimum sustained yield in the affected stocks (Junge 1970). Continued high harvest rates combined with shrinking harvestable surpluses would have created a downward spiral and rapid decline in total production as was observed (Figures 14 and 15). The degradation of freshwater habitat and the loss of biodiversity (life histories) in chinook salmon was more detrimental than high harvest rates in the long run because the loss of biodiversity and habitat quality limited the possibility of recovery after harvest was brought under control. In addition, the loss of production due to habitat degradation would have focused harvest on fewer stocks causing a rapid decline in escapement in areas such as the Snake River and upper Columbia River.

After 1920, as the fishery shifted emphasis to fall chinook, overall harvest of chinook salmon went into decline. While overharvest and habitat destruction contributed to the rate and depth of the decline, there were natural climatic factors contributing to the decline and probably acting synergistically with the human impacts. The region was experiencing a shift in climate to hot/dry conditions and lower ocean productivities. Attempts to stabilize production during a period of natural decline through the use of hatcheries were probably counter productive (Lichatowich *in press*). Following 1938, the construction of mainstem dams and continued habitat degradation in the subbasins prevented recovery to historic levels. The mainstem dams also introduced ecological change in the mainstem Columbia. Those changes reduced habitat quality for juvenile chinook salmon and reduced connectivity between the mainstem and estuarine habitats.

Table 5. Habitat suitability for juvenile chinook salmon in the lower reaches of the study subbasins.

Subbasin	Comments on Habitat	Source
Yakima	Lower river below Prosser (RM 47.1) frequently exceeds 75°F and occasionally reaches 80°F in July and August rendering the lower river uninhabitable by salmonids.	CTYIN et al. 1990
Tucannon	Water temperatures in lower river at or above lethal levels.	WDF et al. 1990
Umatilla	Lower 32 miles subject to irrigation depleted flows and temperatures exceeding upper lethal limits for salmonids.	CTUIR and ODFW 1990
John Day	Juvenile chinook salmon generally not found in the river where temperatures reach 68°F. High stream temperature eliminates juvenile rearing habitat in the lower river.	Lindsay et al. 1981, ODFW et al. 1990
Deschutes	In the mainstem Deschutes River, summer temperatures are adequate for chinook salmon. However, there are temperature problems in the lower reaches of the tributaries where spring chinook salmon spawn. In addition *Ceratomyxa shasta* limit the survival of juvenile chinook salmon in the mainstem through the summer months.	Ratliff 1981, ODFW and CTWSR 1990

This study has pointed to the need for restoration planning that employs a greater use of historical reconstruction and a more inclusive analysis of the salmon's life history. As W. F. Thompson (1959 p. 208) pointed out in our management of Pacific salmon, we attach "far greater importance to that which we see than to that which we do not." One way fishery managers "see" is through the conceptual frameworks and hypotheses that guide specific studies or restoration activities. When managers simplify the system in order to model it, and in the process ignore environmental history, habitat connectivity, life history diversity, or historic conditions of the habitat, their vision is restricted. One result of restricted vision is inadequate problem definition and solution development. Focus is placed on hatcheries and escapements while important contributions to productivity such as life history diversity and habitat connectivity remain outside our vision.

Managers should not abandon models of simplified segments of the salmon's life history and habitat. However, those models and the programs derived from them must be embedded in a broader conceptual framework. The models should be designed to address hypotheses derived from the broader framework. This study is one step in the process of constructing a more inclusive conceptual framework.

DISCUSSION

Biodiversity Hypothesis

The purpose of this study, stated at the beginning of this report, was to evaluate the status of chinook salmon in the streams flowing through the steppe or shrub-steppe ecological zone. The analysis was guided by the working hypothesis that declines in abundance of chinook salmon were due in part to the loss of biodiversity — intrapopulation life history diversity. There is insufficient information to reject the hypothesis. On the other hand, the analysis did not develop conclusive support for the hypothesis. This result is not surprising since the decline in abundance of chinook salmon began before appropriate data on life histories were collected. On balance, the information presented in this report supports the original working hypothesis. The study has permitted a refinement of the original hypothesis which is presented in this section.

Development of a modern industrial economy in the Columbia Basin fragmented salmon habitat and eliminated much of the rearing areas used by juvenile chinook salmon. By 1930, 50 percent of the best spawning and rearing areas had been destroyed or degraded (OFC 19331. For Pacific salmon, where migration is a central feature of the juvenile and adult life history, the connectivity among habitats — tributaries, subbasin, mainstem, estuary — is a critical component of ecosystem health (Lichatowich et al. 1995). Salmon habitats can be thought of as a series of seasonally important places where salmon carry out their life histories (Thompson 1959). The presence of those places (structural habitat features) is important but so is the ability to freely move between them at the appropriate times. Loss of connectivity for part of the natural migratory period eliminates life history diversity in a stock.

Chinook salmon are generally characterized as-preferring larger rivers and larger tributaries of rivers. They tend to spawn in deeper water and in larger gravel than the other species of Pacific salmon (Scott and Crossmen 1973). if the adult life histories evolved to utilize the larger reaches of rivers, is it not reasonable to assume that juvenile life histories also evolved to use the larger, lower reaches of tributaries and mainstems of river basins?

The early life history and freshwater distribution of juvenile chinook salmon in Oregon's coastal rivers has been described in this way:

> *"Immediately after emergence from the gravel, distribution of juveniles is restricted to the areas within the river basin where adults spawned, which usually include low to moderate gradient reaches of the mainstems and larger tributaries. By late spring, underyearlings*

are generally well distributed downstream throughout the mainstem riverine reaches and the freshwater tidal reaches of estuaries. We believe that the extent to which some juveniles remain in the riverine reaches during the summer is related to <u>water temperature</u> femphasis added), with relatively cooler systems supporting rearing juveniles over a more extended duration. Even in rivers that support a population of rearing juveniles for extended periods, an essentially constant flow of juveniles moving downstream probably occurs. We believe the larger juveniles have a greater tendency than smaller juveniles to move downstream," (Nicholas and Hankin 1989 p. 5 and 8).

In Oregon's coastal basins, the subyearling migrant life history (ocean type) dominates both spring and fall races of chinook salmon. About 95 percent of returning adults exhibited the ocean type life history. The Umpqua River is an exception. In the Umpqua River, both stream and ocean type life histories are strong components of the spring chinook salmon population (Nicholas and Hankin 1989).

The quotation from Nicholas and Hankin (1989) includes four important points: 1) continuous downstream migration; 2) the influence of temperature on use of the riverine reaches; 3) the selective movement of larger juveniles; and 4) the importance of the mainstem and estuary as rearing areas. Continuous downstream migration of juvenile chinook salmon is not unique to Oregon's coastal basins. Rich (1920) concluded that juvenile chinook salmon in the Columbia River migrated throughout the entire year with the major migration period from June through October. Rich (1920) speculated that the juvenile chinook salmon migrating at different times in the Columbia River originated in different tributaries with the progressively later migrating fish coming from tributaries further upstream. Further north in the Nanaimo River, juvenile chinook salmon migrate to sea in three pulses one shortly after emergence, a few months later after a short period of freshwater rearing, and the final group in the spring of the following year. Although the migration was divided into three distinct times of entry to sea, there was a downstream movement by all groups during the first summer. The different times of migration were related to the location where the spawning took place (Carl and Healey 1984). In some streams, juvenile chinook salmon undertake a slow rearing migration through the mainstems (Beauchamp et al. 1983).

Rearing areas in the mainstems downstream from spawning areas appear to be important in chinook salmon. Even juvenile chinook that overwinter in freshwater often leave the tributaries and move into the mainstem to rear in larger pools through the winter (Healey 1991). In the Columbia Basin, this pattern has been observed in the Yakima River (CTYIN et al. 1990), Grande Ronde River (Burck 1993), Deschutes River (Lindsay et al. 1989), and Lemhi River (Keifer et al. 1993).

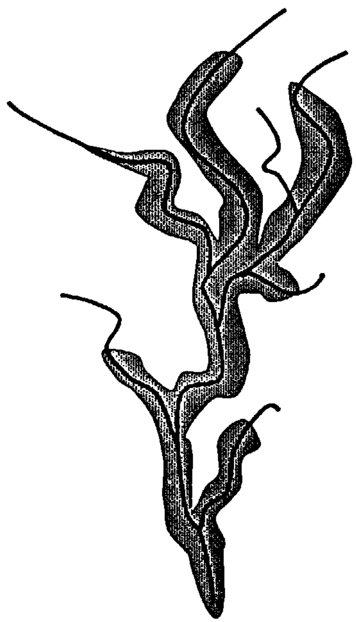
Channel morphology and hydraulics suggest that habitat in the lower reaches of streams is more stable than the upriver areas or tributaries (Naiman et al. 1992; Baxter 1961). The continuous downstream movement of juvenile chinook salmon is in essence a migration towards what were historically the natural centers of habitat stability in the lower reaches of larger tributaries and the mainstem. Today those areas are death traps due to lethal temperatures, predators and mortality at dams.

The continuous downstream migration of juvenile chinook salmon is accomplished by the selective movement of the larger individuals in a population (Nicholas and Hankin 1989). Migration of larger juveniles has been observed in the Columbia River (Rich 1920) and in chinook salmon transplanted to a Michigan stream (Carl 1984). This migration pattern might be explained in this way: Since size is a strong component of mortality rates (Roff 1992) and the lower reaches of rivers historically offered the potential for more stable habitats, the movement of larger juveniles to lower stream reaches has reinforcing survival value.

The lower reaches of mid-Columbia Subbasins have been degraded to the point they are lethal to juvenile salmon (Table 5). Habitat degradation in the lower reaches is largely the result of irrigation withdrawals, grazing and timber harvest. The former reduces flow and influences temperatures. The latter has reduced riparian cover impacting habitat quality and also elevating stream temperatures. The loss of lower mainstems of the subbasins and significant tributaries of subbasins has fragmented the habitat of chinook salmon, in particular the habitat of juvenile summer and spring chinook salmon. Habitat fragmentation results from a loss of connectivity among stream reaches which isolates juvenile chinook salmon in the upper reaches of a basin. Juvenile chinook salmon are blocked from completing their normal migration and are confined to refugia (Figures 40-41). The smaller streams in the upper reaches of the basin — the current refugia — were historically less stable and less productive than the lower reaches of the subbasins and mainstems — the reaches where juvenile chinook salmon historically migrated to in a continuous stream through the spring, summer and fall.

Although juvenile chinook salmon may have migrated in a continuous stream, those movement patterns might be partitioned into three overlapping migrations: the first in early spring consisting of fry and yearling smolts, the second in midsummer consisting of subyearling migrants destined to enter the sea that year, and a third downstream movement of subyearlings in the fall. Juveniles in the latter migration go to sea the following spring (Figures 40-41). Within a given subbasin, when spring chinook salmon have sufficient growth opportunity and

A



B

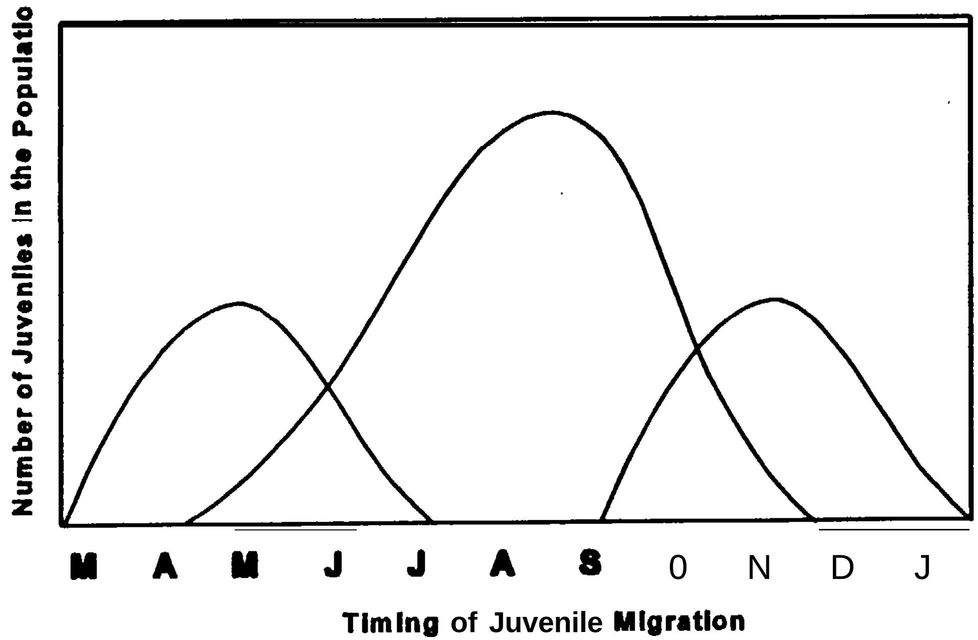


Figure 40. Hypothetical portrayal of highly connected habitats (shaded area in A) in a watershed and the distribution of migration patterns of juvenile chinook salmon in the same basin (B).

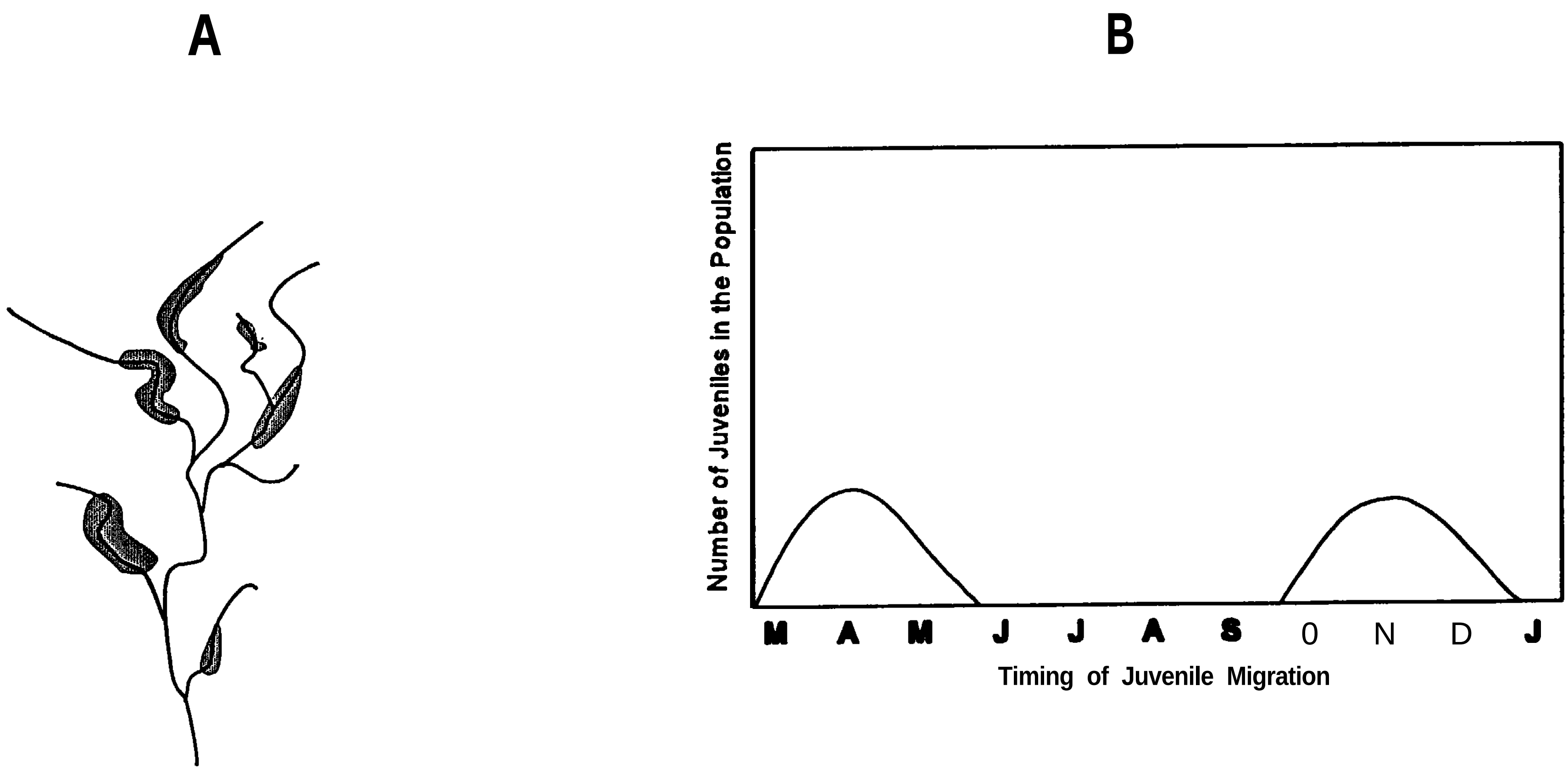


Figure 41. **Hypothetical portrayal of fragmented habitats (shaded area A) disconnected from the lower reaches of tributaries and the mainstem by lethal conditions and the resulting migration patterns of juvenile chinook salmon in the same basin (B).**

habitat connectivity, the ocean type life history pattern emerges as an important component of a population's productivity. As habitats are fragmented, the ocean type life history is reduced or eliminated (Figures 40-41).

How might the hypothesis presented here alter our thinking or approaches to restoration? Here is an example:

Suppose a subbasin has lost connectivity with the mainstem with a resultant loss of life history diversity and productivity of 2the stock. One conventional approach is to "open up" new habitat in the upper reaches of the subbasin by laddering falls or other natural barriers. When the problem is viewed from the life history/habitat perspective, it becomes obvious that creating more habitat in the upper basin will not reduce the lower river production constraint.

The decline in abundance of chinook salmon, in particular the spring and summer races, was the outcome of habitat degradation and persistent high harvest rates. Habitat degradation reduced life history diversity and productivity of the spring and summer races. Continued harvest aggravated the effects of lost biodiversity. Further habitat degradation and continued harvest accelerated the rate of decline during a period of hot/dry climate and low ocean productivity. By the 1940s, a firmly entrenched agricultural system that diverted water and destroyed riparian vegetation and mortality at mainstem dams prevented any possibility of recovery to pre-1920s production levels.

The biodiversity hypothesis illustrated in Figures 40 and 41 is a consequence of viewing the decline of salmon through the lens of a different conceptual framework — a framework articulated in the early sections of this report. The life history-habitat or biodiversity hypothesis should not be considered an all-encompassing solution or approach to the restoration of Pacific salmon in the Columbia River, on the other hand, the biodiversity hypothesis and its conceptual framework should not be ignored. In a basin the size of the Columbia River, there is room for and in fact a need for conceptual pluralism. The alternative to conceptual pluralism is consensus driven dogma which stifles the creativity and problem solving power of science. At a minimum the conceptual framework for large programs should be explicitly stated. Too often that is not the case (e.g., Whitney et al. 1993).

Uncertainty

It is uncertain whether the conditions in the lower reaches of the study subbasins ever did maintain salmon habitat through the summer months, especially temperatures suitable for summer rearing and migration of juvenile chinook salmon. The study subbasins are all high desert streams where warm summer climate and low rainfall are normal. Conditions in the lower reaches of those streams may have always been marginal or lethal.

There can be little doubt that these subbasins represent marginal habitat and that they were very sensitive to degradation following settlement. Severe habitat degradation took place early, before the turn of the century, and there is at least anecdotal information that salmon populations were much larger in the study basins historically than today. If the biodiversity hypothesis for the mid-Columbia streams is rejected, one would have to conclude as an alternative that the millions of yearling juveniles (stream type) needed to produce the historic abundance of spring and summer chinook salmon were capable of rearing in the restricted habitats available today.

The subbasins included in this study may have undergone natural restriction in life history diversity in response to climate cycles. The hot/dry climate during the 1920s, 1930s, and 1940s, for example, might have naturally reduced flow and elevated temperatures eliminating or reducing the subyearling migrant life history. The decline in harvest of chinook salmon initiated in 1920 (Figure 38) was in part a natural decline. The rate of the decline and the depth of the trough was aggravated by habitat degradation and harvest. The natural loss and recovery of life history patterns and populations with changing climate and habitat suitability is consistent with the concept of metapopulation structure (Hanski and Gilpin 1991; Reiman and McIntyre 1993). Irrigation withdrawals, habitat degradation and mainstem dams prevented the natural recovery of chinook salmon following a shift to a more favorable climate pattern. What recovery that did occur (E and F in Figure 35) did not even begin to approach the former abundance.

The uncertainty regarding natural temperature regimes can be addressed in two ways. The spacing of growth rings on freshwater mussels are an accurate reflection of the temperature of the mussel's environment. Stream temperatures can be backcalculated from the increments of shell growth of freshwater mussels (Chatters *in* press). Shell middens in the Yakima Basin could be examined and historic temperatures reconstructed. This approach has a reasonable chance of successfully resolving the question, "Were the predevelopment temperatures in the lower Yakima River compatible with usage by juvenile salmon?" (personal communication; James Chatters, North American Paleoscience, Richland, WA).

An alternative approach is the restoration of natural riparian zones and flows in a selected subbasin to determine if the subyearling life history reexpresses itself. This approach would be expensive and it would disrupt the patterns of land and water use that have been in place for a century or more. However, restoring habitat connectivity is consistent with the restoration of salmon from within an ecosystem perspective. Approaching restoration from an ecosystem perspective, which seems to be the emerging consensus, will at some point require adaptive

programs scaled to the watershed or ecosystem level of organization. Reconnecting the parts of the subbasin in a way that reestablishes life history diversity could prove to be as beneficial to salmon production and productivity as improving survival at the mainstem dams. Restoring connectivity between the mainstem and the subbasin, however, will probably be much more difficult to achieve.

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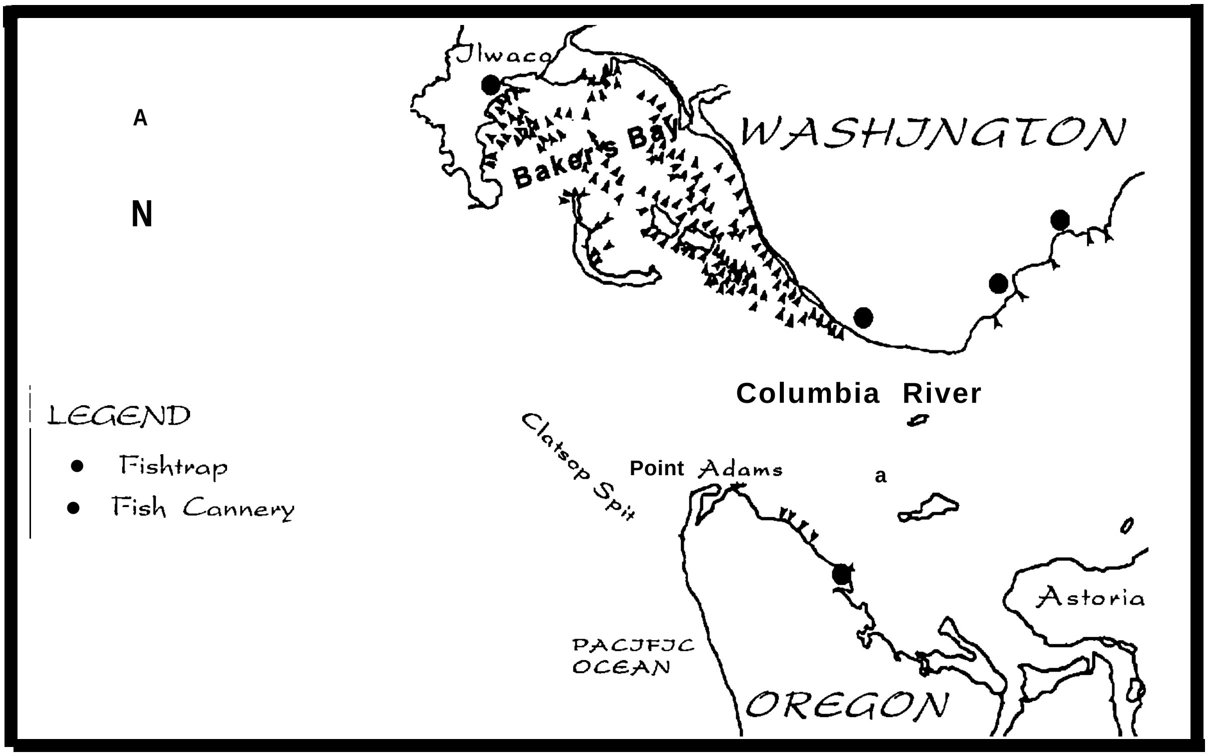

A History of Frameworks Used in the Management of Columbia River Chinook Salmon

May 1996

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EXECUTIVE SUMMARY

Lichatowich and Mobrand (1995) analyzed the decline of chinook salmon in the Columbia River from the perspective of natural production cycles, habitat degradation and changes in life history patterns. This report also analyzes the decline of chinook salmon, but from a different perspective, the management perspective. The years from 1866 to the present were divided into four periods, representing major shifts in harvest and salmon population status. In each period, three questions were asked: What was the status of the fishery? How did managers respond to that status? What was the underlying management framework? The last question was most important. As used in this report, management framework is the set of assumptions and principles that give direction to management activities. The management framework determines how information is interpreted, it determines what problems (limitations on production) are identified and as a result establishes the range of solutions that are appropriate.

The report focuses on artificial propagation because it was the first management activity and it has been a dominant part of the management programs for the last 120 years. Had the report focused on harvest management or habitat protection the overall message and conclusions would have remained the same.

The four periods were 1866 to 1888, initial development of the fishery; 1889 to 1920, a period of apparent stability; 1921 to 1958, a period of major decline; and 1959 to the present, a period of persistent depletion (Lichatowich and Mobrand 1995). Major conclusions for each period are summarized below:

1866 to 1888

Status Rapid increase in catch followed by a sharp decline from the peak of 1883. Average annual harvest was 24 million pounds. The canning industry grew rapidly in economic importance.

Response Minimal laws to regulate harvest and protect habitat were enacted, however they were not enforced. Salmon managers and the canning industry accepted artificial propagation as an alternative to conservation.

Management Framework Laissez-faire access to natural resources and a belief that man must control and dominate nature were the prevailing world view. Theory and practice of salmon management conformed to that view. Managers believed that artificial propagation would give humans complete control over salmon production, and provide an unlimited supply of fish.

1889 to 1920

Status Total harvest of chinook salmon was relatively stable and achieved an annual average harvest of 25 million pounds. The fishery intensified with a significant depletion of adult spawners in the upper basin. The spring run declined and total catch had to be maintained by harvesting more of the fall run fish, which cannery operators considered inferior.

Response Salmon managers maintained their belief that artificial propagation could overcome the effects of excessive harvest and habitat degradation. Irrigation, mining, grazing and timber harvest were rapidly degrading the quality of salmon habitat. Harvest restrictions were still minimal, but after 1908, Oregon and Washington enacted uniform harvest regulations.

Management Framework Justification for a strong reliance on artificial propagation shifted from the religious-based mandate that man should control nature to the Progressive vision of conservation: Natural resources should be managed for maximum economic efficiency by technical experts. Hatcheries easily made the transition to this new set of values. The basic assumption that humans can and should simplify and control salmon production was retained.

1921 to 1958

Status Chinook harvest declined throughout this period to an overall annual average of 15 million pounds. The fishery underwent a major shift from in-river to troll fisheries. The construction of mainstem dams added a major new factor in the degradation of salmon habitat.

Response As the salmon declined and traditional approaches to management appeared unable to arrest the depletion, the need to place management on a scientific footing was recognized. The first comprehensive surveys of salmon habitat in the basin were completed. The depleted status of the salmon resulted in several attempts to share scientific information among salmon managers and to develop restoration plans. Managers ignored scientific information on the stock structure of the salmon and the past failures of hatcheries to reverse the salmon's decline and turned to artificial propagation as the primary means of mitigating the effects of mainstem dams.

Management Framework The massive development of the basin's water resources for power production, irrigation, flood control and transportation was enhanced by the post World War II science of systems engineering. The same approach was also popular in ecology. Engineers and many ecologists assumed the machine was a reasonable model of the systems they sought to analyze, improve or manage. Artificial propagation easily made the transition to the new framework because, like the previous frameworks, control and simplification of salmon production were important elements. The artificial production system achieved a higher level of simplification by circumventing most of the salmon's fresh water life history through the release of smolts.

1959 to present

Status The average harvest of chinook salmon dropped to five million pounds, although that figure does not include troll caught fish landed outside the basin. The Snake River sockeye and chinook salmon were listed under the federal Endangered Species Act. Development of the basin's water resources was completed and natural flow patterns were altered. Habitat in many subbasins continued to decline.

Response The full development of the hydro system was met with a massive increase in artificial propagation. Several in-river fisheries were closed and the commercial season was significantly reduced. Scientific research continued to show the importance of the salmon's stock structure and identified artificial propagation as contributing to the decline of natural production. The

Northwest Power Planning Council recognized the importance of biodiversity and natural production in its Fish and Wildlife Program.

Management Framework In spite of a long history of persistent decline, failures to reverse those declines in chinook salmon production and scientific evidence questioning the management framework, the basic assumption that control and a simplification of the production system could restore salmon production remained intact.

There are signs that a new framework based on an ecosystem perspective is emerging out of the present crisis. The basic assumptions of the emerging framework appear to be diametrically opposed to those underlying the current framework: restoration and protection of ecological processes vs the circumvention of those processes; controlling human behavior that limits or destroys ecological processes vs the attempt to control and improve nature; and promoting biological and habitat diversity vs simplifying the production process in the act of improving it. Adopting a new framework is a difficult undertaking. It could be argued that the existing framework hasn't changed much in the last 120 years. The region is in the midst of transitions, though which way it will proceed is uncertain. If the changes, like in the past, are primarily superficial, the region can only expect that the present crisis will deepen.

The current status of Pacific salmon in the Columbia Basin is not what salmon managers intended to achieve. Salmon managers, culturists and researchers were a hard working group of professionals dedicated to maintaining the "supply" of salmon. Given those good intentions, How did reality deviate so far from expectations? A major part of the answer to that question is found in the framework, the set of assumptions and principles that made up management's underlying foundation. The framework which was so taken for granted that it was rarely referred to or discussed, turned out to be a major determinant of the salmon's future. However, it was not only salmon management that suffered under an inadequate framework.

Perhaps William Cronon described the situation best in his foreword to Susan Langston's book on forest management in the Blue Mountains (Langston 1995).

> ***"The problems that foresters faced in the Blue Mountains flowed as much from their own scientific paradigms as from the ecological phenomena going on in the forest itself - phenomena that those paradigms sometimes rendered all too invisible. The moral of this story should be clear. Even well-intentioned management can have disastrous consequences if it is predicated on the wrong assumption, and*** yet ***testing those assumptions is always much harder than people realize. To do so, we must realize that ecosystems are profoundly historical, meaning that they exist in time and are the products as much of their own past as of the timelessly abstract processes we think we see going on in them. "***

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A HISTORY OF FRAMEWORKS USED IN THE MANAGEMENT OF COLUMBIA RIVER CHINOOK SALMON

I. INTRODUCTION

The purpose of this report is to describe the history of salmon management in the Columbia Basin. Salmon management is a broad subject with a long history; the scope of this report is limited as follows: 1) The historical record is divided into four time periods that correspond to changes in the overall pattern of chinook salmon harvest in the basin 2) Artificial propagation has been a dominant management tool for the past 120 years; it was also the first management activity. This report emphasizes the hatchery program and uses it to illustrate changes in management philosophy and direction. 3) In each time period, the status of chinook salmon in the basin is reviewed, the management activities (harvest, habitat and hatcheries) are described and the framework which guided salmon management in the basin is described. The report is not a chronology of research projects, regulations, habitat projects or hatchery operations, although all of those are discussed if they help illustrate resource status, management response to that status and the underlying framework.

A. APPROACH AND ORGANIZATION OF THE STUDY

This review of management history is organized into time periods bounded by major changes in the harvest of chinook salmon in the Columbia River. We focused on chinook salmon because they were the most abundant anadromous salmonid in the basin and they were the primary target of the early fisheries (Craig and Hacker 1940). The harvest of chinook salmon between 1866 and 1992 can be divided into four distinct phases: 1866 to 1888, when the fishery was gearing up; 1889 to 1920, a period of apparent stability; 1921 to 1958, a period of major decline; and 1959 to the present, a period of persistent depletion (Figure 1). Management in each of the time periods is analyzed by answering three questions: What was the status of the fishery and how did managers interpret the status at the time? How did management respond to the change in status in terms of hatchery operations, harvest regulations and habitat protection? What was the dominant management framework? ***The last question is most important. The management framework is the set of assumptions, theories and principles that give direction to management activities. The management framework determines how information is interpreted, it determines what problems (limitations on production) are identified and as a result establishes the range of solutions that are appropriate.*** Unfortunately, the management framework is rarely explicitly described; it had to be inferred from the management activities carried out during the different time periods.

B. THE VALUE OF HISTORICAL ANALYSIS

Historical reconstruction is not a favorite pursuit of salmon managers and it has been equated to driving forward down the road while only looking into the rear view mirror (Lichatowich ***in***

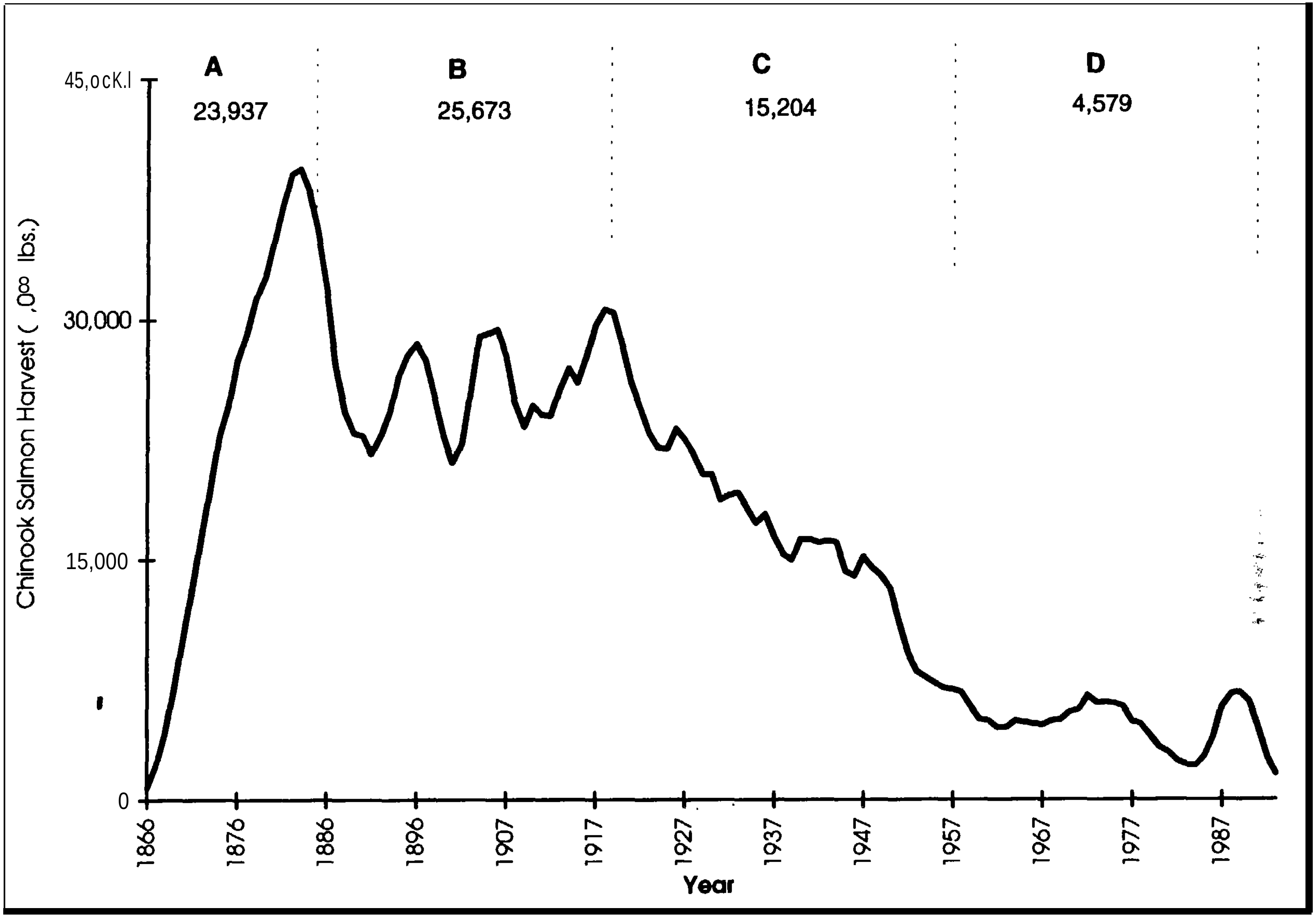

Figure 1. Five year running average of chinook salmon harvest in the Columbia River 1866-1992. Time periods A-D described in the text. Numbers within each period are average harvest.
(Source: *Lichatowich* and *Mobrand 1995*)

press). We don’t propose that mangers spend all their time reconstructing the history of the resource or its management, however, all drivers know it is essential to occasionally glance in the rear view mirror. Salmon management would benefit from an occasional examination of its history. The failure to recognize the importance of history in salmon management in part stems from the machine metaphor for ecosystems that became popular following World War II (Golley 1993). When ecosystems are equated to machines the value of both historical analysis and careful consideration of the future is reduced or eliminated. Machines work today the same way they did yesterday and the way they will tomorrow (Botkin 1990). Fisheries managers are as reluctant to consider the future as they are to reconstruct the past, which in part explains the consistent failure to meet escapement and restoration targets.

Historical analysis is important for another reason. Ecosystems and their associated management institutions are products of their histories: The geological and erosional histories of the land forms and river channels, the evolutionary history of the biota in the watershed and the history of human economies and cultures. Those histories establish the trajectory of an ecosystem’s development. They determine the system’s present state and the range of possibilities for future change and development. An understanding of those trajectories is important to the development of rational management programs and restoration expectations.

But still the question remains valid: Why should managers study the history of salmon management in the Columbia River? As Mundie (1977) succinctly put it: “Inadequate knowledge of the ecological needs of the salmon has not been a prime cause of their decline. Decisions have been made knowingly.” In other words the present crisis is an outcome of the failure to consider the persistence of salmon in decision making (National Marine Fisheries Service 1995 p. II-10). The clear implication is that the crisis is a result of a failure in salmon management in addition to the destructive economic development strategies implemented in the region. Sustainable recovery of even a small part of the once productive runs of Pacific salmon in the Columbia River, will require an examination of how, when and why past management decisions were made and their contribution to the current status of the salmon. We have to identify all the dimensions of the problem before we can hope to devise an adequate solution.

Historical reconstruction must refrain from being judgmental about past practices. Hindsight often offers more clarity and insight than could have been possible at the time decisions were made or programs implemented. Management was and is practiced in a social environment, and within that environment managers are influenced by the state of science, community values and sometimes by long-standing but untested assumptions or myths. The combination of all these comprise the framework within which salmon management is practiced. Past management may be viewed as inadequate when examined by today’s community values and scientific understanding, but it was in many cases consistent with the science and community values of the time. Even a careful review of past management in its proper historical context, will often seem like an expose rather than an objective statement (Robbins 1994). It is our hope this report gives the latter rather than the former impression.

II. 1866 TO 1888

A. STATUS OVERVIEW

The commercial harvest of Pacific salmon dramatically escalated after 1866 following the introduction and development of canning technology and the development of domestic and foreign markets for the canned product (Figure 2). In 1866 George, William and Robert Hume along with Andrew Hapgood built the first cannery near Eagle Cliff, Washington and in eight years the industry had grown to 13 canneries, 300 boats and 600 workers. The next three years saw even more rapid growth. By 1877,30 canneries were being supplied by 1,000 boats and the industry employed 6,000 laborers (Hayden 1930). The number of operating canneries reached a peak of 39 in 1883 and declined steadily thereafter (Craig and Hacker 1940).

Although the most intensive fishery was located in the lower 75 miles of the river, salmon were harvested throughout the river. Gill nets harvested most of the salmon, although traps, seines and fish wheels also caught large numbers. In 1883, the year of the peak harvest of chinook salmon, 1,700 gillnet boats fished in the Columbia River (Smith 1979). The first modem fish traps were built in 1879 and their number increased rapidly, especially in Baker Bay near the mouth of the river (Figure 3) and by 1886, 156 traps were intercepting salmon in the lower river (Craig and Hacker 1940). Fish wheels first appeared on the river in 1879 (Donaldson and Cramer 197 1) and by 1889,57 fish wheels were operating in an area 30 miles above Bonneville and near Celilo Falls. The best wheels could catch 6,000 fish a day during the run (Craig and Hacker 1940). Seine fisheries were pursued in the lower river at places like Sand Island and in the upper basin below the Boise River in the mainstem Snake River.

The increase in fishing gear was rapid, intense and largely uncontrolled. Without any kind of government control over the gear and the fishery in the early years, harvest followed the model described by Hardin (1968) as the “tragedy of the commons.” By 1880, fishing pressure and harvest in the lower river increased so much that canneries located only 20 miles up river had to send their fishermen to the mouth to ensure a supply of fish (Jordan and Gilbert 1887).

The fishery for chinook salmon peaked in 1883 at 42,799,OOO pounds and declined rapidly to 18135,000 pounds in 1889 (Figure 2).

The earliest Euroamericans in the Pacific Northwest viewed the abundance of salmon as inexhaustible (Gibson 1985) and this attitude prevailed during the initial decades of the commercial fishery for Pacific salmon (Hume 1893). However by 1875, cannery operators alarmed by the intensity of the fishery petitioned’ congress for legislation to restrict the harvest of salmon and provide for artificial propagation in the basin (Hayden 1930). Congress having no clear jurisdiction did not act but Spencer Baird, The U. S. Fish Commissioner, told the industry that artificial propagation would eliminate the need to regulate harvest (Baird 1875).

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[1] Hayden (1930) indicates that the cannery operators submitted the petition, however, Baird (1875) indicates that the petition came from the Oregon Legislature.

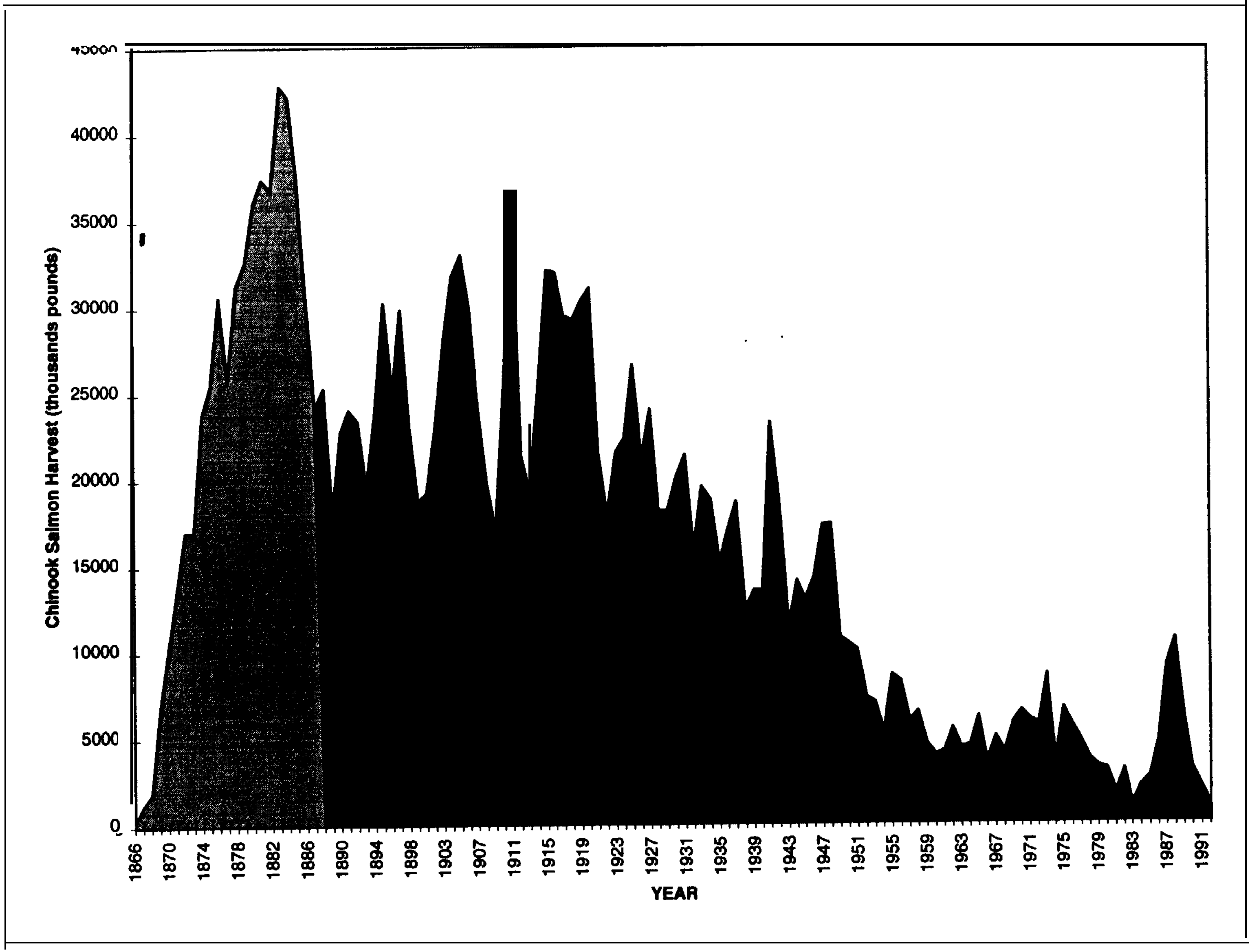

Figure 2. The annual harvest of chinook salmon in the Columbia Basin. The highlighted region (1866- 888) is discussed in the text (*Source: Beiningen 1976; ODFW and WDF 1993*)

Figure 3. Lower Columbia River showing the concentration of fish traps in Baker's Bay in 1887. *(Source: Map, U. S. Engineer Office, Portland,* Oregon *August 23, 1887)*

The spring run of chinook salmon made the highest quality canned product so it was prized by the canneries and targeted by the fishermen (Craig and Hacker 1940; DeLoach 1939) In 1877, two years after the petition to congress and coinciding with the first significant decline in catch (Figure l), the cannery operators became more concerned because the prized spring run appeared to be rapidly declining. To increase the supply of spring run fish, several of the cannery owners formed the Oregon and Washington Fish Propagation Company, raised $21,000 in donations, and built a hatchery on the Clackamas River (Hayden 1930; Stone 1879). In 1877, there were three salmon hatcheries on the West Coast: the Baird Station (also called the McCloud Hatchery) in the Sacramento Basin operated by Livingston Stone, R. D. Hume's hatchery on the Rogue River and the Clackamas Hatchery in the Columbia Basin.

B. MANAGEMENT ACTIVITIES

1. Hatcheries

The first hatchery program in the Columbia River was short lived, which suggests that the industry was not convinced that conservation measures, even hatcheries, were in their best interest. An exception was R. D. Hume, who was predicting collapse of the fishery unless conservation measures and hatcheries were taken seriously (Hume 1893). The Oregon and Washington Fish Propagation Company built their hatchery on the Clackamas River with the help of Livingston Stone, but they operated the facility for only five years before closing it in 1881 (apparently due to lack of funds). After the decline in harvest in 1877, the catch increased and was still increasing in 1881 when the hatchery was closed (Figure 1). The state of Oregon reopened the hatchery in 1888, one year after the Oregon Legislature established the State Board of Fish Commissioners. In 1889, the state turned the hatchery over to the U. S. Fish Commission (Cobb 1930).

Artificial propagation of Pacific salmon began in 1872 and by 1883, even though there was no evidence establishing the effectiveness of hatcheries, they were no longer considered experiments and their success was claimed to be fully established. In a discussion of fish culture at the 1883 World Fisheries Congress, George Brown Goode of the U. S. Fish Commission claimed the salmon industry on the Columbia was under complete control of the fish culturists (Maitland 1884). which is difficult to understand since the only hatchery in the basin had been closed for two years when he made those remarks. Even though artificial propagation lacked solid evidence of success, it did not lack enthusiasm[2] on the part of its supporters and that optimism was reflected in the policy of the U. S. Fish Commission. Hatcheries were the primary management activity of the Commission, and it was their policy that it was easier to make fish so abundant through artificial propagation that regulation of harvest would be unnecessary (Goode 1884 p. 1157).

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[2] Contrary to the impression given by the closure of their hatchery, cannery operators supported artificial propagation as long as the government paid for it (DeLoach 1939).

The U. S. Fish Commission's artificial propagation program had two objectives:

1) To arrive at a thorough knowledge of the life history from beginning to end of every species of economic value, the histories of the animals and the plants upon which they feed or upon which their food is nourished, the histories of their enemies and friends, and the friends and foes of their enemies and friends as well as the currents, temperatures and other physical phenomena of the waters in relation to migration, reproduction and growth.

2) To apply this knowledge in such a practical manner that every form of fish shall be at least as thoroughly under control as now the salmon, the shad, the alewife, the carp and the whitefish. (Goode 1884 p. 1162)

The first objective recognized the need to understand the biology and ecology of the propagated fish throughout their life cycle and in relation to the physical environment. If the first objective had been implemented, the commission would have discovered that the second objective was overly optimistic at least for the anadromous Pacific salmon.[3] The first objective received little attention, although the U. S. Fish Commission did undertake extensive studies of marine fishes on the Atlantic Coast (Allard 1978), with respect to Pacific salmon. For example, in 1879 Livingston Stone asked the U. S. Fish Commission to assign a trained biologist to the Baird Hatchery on the Sacramento River. A biologist could have started work on Objective 1, but the request was turned down. Had Stone's request been granted it might have established a precedent, and created a different approach and direction in the hatchery program and quite possibly, our knowledge of the salmon and their status might have been very different than they are today (Hedgepeth 1941).

2. Harvest Regulation

In the same year that the Oregon and Washington Fish Propagation Company opened its hatchery on the Clackamas River (1877) the first attempts to regulate and control the fishery were made. The territorial legislature of Washington closed the fishery on its side of the Columbia River in March, April, August and September. A year later, the Oregon Legislature enacted the same closure with one difference: April was open except during weekend closures. In 1881, Washington reopened the fishery in September (Wendler 1966). Although the regulations were enacted, their enforcement was often less than enthusiastic, and in some cases the law was just not enforced. For example, the weekly closure was not enforced in Oregon because the Fish Commissioners believed it would cause a hardship for the fishermen (Oregon Board of Fish Commissioners (OBFC) 1888). Throughout this period there was little effective control of the fishery while great faith was placed in hatcheries to maintain the supply of salmon, even though there was only one interim hatchery operating.

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[3] This does not mean that control of production is impossible. Net pens and captive brood technology have achieved a high level of control over production. However, it has not been possible for technology to control production and still maintain the abundance of salmon present in the late 1800s or even the mid-1900s.

3. Habitat

In November of 1852, James G. Swan was traveling by sea from San Francisco when he recorded in his diary that the Columbia River was in flood stage and that the water 30 miles off the mouth of the river was covered with sawdust and boards (Swan 1857). It was common practice to dump sawdust into streams near a lumber mill so it could be carried out during high water. The presence of so much sawdust so far out to sea suggests that the tributary streams from which the debris came were already undergoing important habitat degradation. The problem was recognized by territorial and state legislatures. Washington territory enacted a law to stop the dumping of sawdust in streams in 1876 (Stone 1879) and Oregon followed with a similar law two years later (Johnson 1984).

As soon as permanent settlement got underway in the mid- 18OOs, the Euroamericans began altering stream habitats. West of the Cascade Mountains, stream channels were cleared so rivers could be used to transport people and commodities. Wetlands were drained and diked, and in general the complexity of stream habitats was reduced (Sedell and Luchassa 198 1). In the dryer climate east of the Cascade Mountains, irrigation caused massive direct mortality of juvenile salmon and contributed to habitat degradation. Grazing and mining were also important sources of habitat degradation (Lichatowich and Mobrand 1995; Wissmar et al. 1994).

Logging, grazing and agriculture destroyed riparian vegetation and destabilized stream banks causing increased sediment loads in the rivers. Some indication of the extent of the sedimentation comes from U.S. Army Corps of Engineers. Captain Charles Powell reported significant shoaling in the lower Columbia River in 1887 and attributed the loss of depth to the effect of the large number of gill nets in the lower river fishery (Powell 1887). Powell's observation is an indication of the intensity of the fishery. Rapid filling in of the channel, however, suggests significant destabilization of the basin's tributary streams causing the release of sediments that were deposited in the lower river.

Residents in the Pacific Northwest recognized the potential impact on salmon production as a result of changes in habitat, and the citizens of Oregon were concerned enough about it to include provisions for salmon protection in their territorial constitution of 1848:

> ***"The rivers and streams of water in said territory of Oregon in which salmon are found or to which they resort shall not be obstructed by dam or otherwise, unless such dams or other obstructions are so constructed as to allow salmon to pass freely up or down such rivers or streams. " (cited in Johnson 1984)***

This indicates that problems already existed in 1848 and that they were of sufficient magnitude to compel the territorial leaders to address them in the state's constitution. However, like the fishing regulations, the enforcement of the early habitat protection laws were lax or totally lacking (Wissmar et al. 1994; Johnson 1984).

C. MANAGEMENT FRAMEWORK

Management, when it was attempted during this period, was desultory at best, but that was not inconsistent with the social and scientific context of the time. In the mid-1800s America was undergoing a flowering of science (Kohlstedt 1991) and a renewal of the Baconian Philosophy that scientific knowledge granted technological power and control over nature (White 1967). Nature left alone was wasteful and inefficient and it was man's responsibility and mission to control the natural world, make it more efficient and place it fully in the service of humans. Humans were created to be at the center and somewhat independent of the ecosystems they lived in (White 1967). That attitude is clearly illustrated in Livingston Stone's explanation for the large surplus of salmon eggs deposited in the gravels of the Columbia River every year:

> ***"Nature . . . produces great quantities of seed that nature does not utilize or need. It looks like a vast store that has been providedfor nature, to hold in reserve against the time when the increased population of the earth should need it and the sagacity of man should utilize it. At all events nature has never utilized this reserve, and man finds it already here to meet his wants. "(Stone 1884 p. 21)***

The belief that an excess of salmon eggs was created in anticipation of human needs reflects the view that ecosystems and watersheds were merely warehouses where commodities were stored for man's use (Worster 1977). Earth was a giant factory where humans through their mechanical inventiveness would control the production process. The outcome of human intervention and manipulation of nature was a pastoral Garden of Eden tended by man. Untamed nature was an evil and vicious state; it had to be tamed and made part of the garden or kept at bay (Bottom in press; Worster 1977). This view of the natural world and man's place in it was reinforced and encouraged by government policies.

The governments and the courts acted in a way that protected and even encouraged the ruthless and uncontrolled exploitation of the resources, especially in the frontier west (McEvoy 1986). Businesses that overstepped their bounds and appropriated or destroyed resources held in public trust found a government willing to look the other way. Where exploitation created social costs, such as polluted rivers and depleted salmon populations, those costs were borne by the citizens rather than the offenders (Robbins 1994). Laissez-faire ideology combined synergistically with the belief in man's domination over nature and led to a management framework permitting massive degradation of resources. There were other views of nature, but the proponents of a more benign role for humans, such as the views held by Henry Thoreau and John Muir, were not in the mainstream.

Although competent technicians and biologists such as Livingston Stone, Charles Gilbert and Barton Evermann were accumulating information on the biology of the Pacific salmon, that knowledge was very rudimentary and sometimes erroneous. For example, it was believed that contact with cold, fresh water caused the salmon to run into the rivers in spring before their gonads were fully developed. According to this theory, the size of the spring run of chinook salmon in any river was determined by the amount of snow melt. So a large spring freshet and large spring run of chinook salmon meant fewer adults left in the ocean for the fall run (Jordan and Gilbert 1887). Important aspects of salmon biology such as death after spawning and homing to the natal stream were the subject of debate. Although, the beginning of an appreciation for the stock structure and its basis for management was emerging as early as 1880 in British Columbia (McDonald 198 1) and 1893 in the U. S. (Hume 1893), biologists generally believed the species of Pacific salmon were genetically uniform (Ricker 1972). Knowledge of the biology of the salmon was rudimentary. Science was over-powered by the social/political attitudes and beliefs to the point that it hardly entered into the management framework except through hatcheries.

Hatcheries fit into and reinforced the social, scientific and political context of the period. Livingston Stone's view of the surplus production of salmon eggs in the Columbia River was consistent with the belief that nature was created for human use. His comment (p. 10) illustrates that scientists interpreted information and developed theory that confirmed the prevailing world view (Bottom in press). Humans could and should control salmon production through artificial propagation, and once that control was achieved, it would permit an unrestrained fishery. Through artificial propagation, humans would assume control over production in much the same way that agriculture controlled the production of plants and animals (Fry 1854). There was another reason hatcheries were a popular management tool. They allowed the region to avoid the otherwise inevitable conflict between habitat degradation and survival of the salmon fishery.

Two events illustrate the interaction between hatcheries, the social goal to control nature and salmon management. In 1875, in response to a request from the Oregon Legislature, Spencer Baird, the U. S. Fish Commissioner, outlined the problems facing the salmon industry on the Columbia River and the solutions to those problems. Baird identified three problems:

- excessive fishing,
- dams, and
- altered habitat.

It is interesting to note that the same basic problems have persisted for 120 years. Although Baird correctly identified the three basic problems, his solution, although consistent with the prevailing framework, proved to be a failure. According to Baird, protecting the fishery through restrictions and regulations was not feasible or desirable. He concluded it was better to spend $15,000 or $20,000 to make salmon so plentiful through artificial propagation that protective regulations would be unnecessary (Baird 1875). Baird reached this conclusion just three years after the first hatchery for Pacific salmon was opened on the Sacramento River. Ninety years later hatcheries began making meaningful contributions to the fishery (CBFWA 1989), but by then most of the original natural productivity of the Pacific salmon in the Columbia River had been destroyed.

Baird's response to the legislature was endorsed by the fishing industry. In 1877, in response to proposed legislation that would have instituted minor restrictions on the fishery, several canners signed a petition to build a hatchery instead of enacting even minor controls on the harvest (Oregonian 1877). Several months later the Oregon and Washington Fish Propagation Company was formed and the Clackamas Hatchery built.

D. SUMMARY

<u>Status</u> Rapid increase in catch followed by a sharp decline from the peak of 1883. Average annual harvest was 24 million pounds. The canning industry grew rapidly in economic importance.

Response Minimal laws to regulate harvest and protect habitat were enacted, however they were not enforced. Salmon managers and the canning industry accepted artificial propagation as an alternative to conservation.

Management Framework Laissez-faire access to natural resources and a belief that man must control and dominate nature were the prevailing world view. Theory and practice of salmon management conformed to that view. Managers believed that artificial propagation would give humans complete control over salmon production, and provide an unlimited supply of fish.

III. 1889 TO 1920

A. STATUS OVERVIEW

The harvest of chinook salmon during this period was variable but without a clear increasing or decreasing trend. Average catch through the period was 25 million pounds (Figure 4) compared to average harvest of about 24 million pounds in the previous period (Figure 1).

In 1895, Marshall McDonald, who succeeded Spencer Baird as the U. S. Commissioner of Fish and Fisheries at the time of his death in 1887, released a report of an investigation of the Columbia River fisheries (McDonald 1895). In the years immediately preceding McDonald's investigation the harvest dropped from a peak of 42 million pounds (1883) to 18 million pounds (1889) and for the next six years which were just prior to -McDonald's report, the catch remained below the peak of 1883 (Figure 4). McDonald attributed the decline to overharvest, and although he acknowledged that a few rivers had been blocked by dams (the Boise River, for example), he assumed the remaining rearing habitat was adequate to maintain the supply of adults if sufficient numbers were allowed to escape the fishery. McDonald believed that the fishery from 1889 to 1893 actually harvested a greater proportion of the run than in previous years even though the harvest was smaller. He based this conclusion on reports of large declines in the number of adults reaching the upper basin. Based on this information, he predicted run size and harvest would continue to decline over the next five years (1894 to 1898). Harvest increased in 1894, reached 30 million pounds in 1895, and declined again in 1899 to 18 million pounds.

In 1892, the fishery employed 5,545 workers. Salmon were harvested by 378 pound nets, 38 seines, 1,314 gill nets, 57 fish wheels and 75 dip nets (McDonald 1895). By 1926, there were 1,790 gill nets, 506 traps, 94 seines, 48 fish wheels, 291 dip nets and 342 trollers fishing salmon in the Columbia River (Smith 1979).

By 1903. a decline in the prime, spring chinook salmon was evident, and to compensate, more of the harvest shifted to the fall run of chinook salmon (Pacific Fisherman 1903) which the cannery operators considered inferior. The decline in the spring run fish had a greater impact on the fishery above The Dalles, so while canneries in the lower river were unable to handle all the catch. canneries further up river were not getting enough fish to operate and had to ship salmon from the lower river (Pacific Fisherman 1903). In addition to a shift in harvest from spring to fall chinook salmon, the fishery started targeting other species. In 1889, canneries began processing sockeye salmon and steelhead for the first time. A few years later, coho and chum salmon were being canned. species that had previously been considered inferior (DeLoach 1939).

B. MANAGEMENT ACTIVITIES

1. Hatcheries

As described in the previous section, the first hatchery in the Columbia Basin was constructed in 1877 and operated until 188 1 when it was closed. The State of Oregon reopened the hatchery in

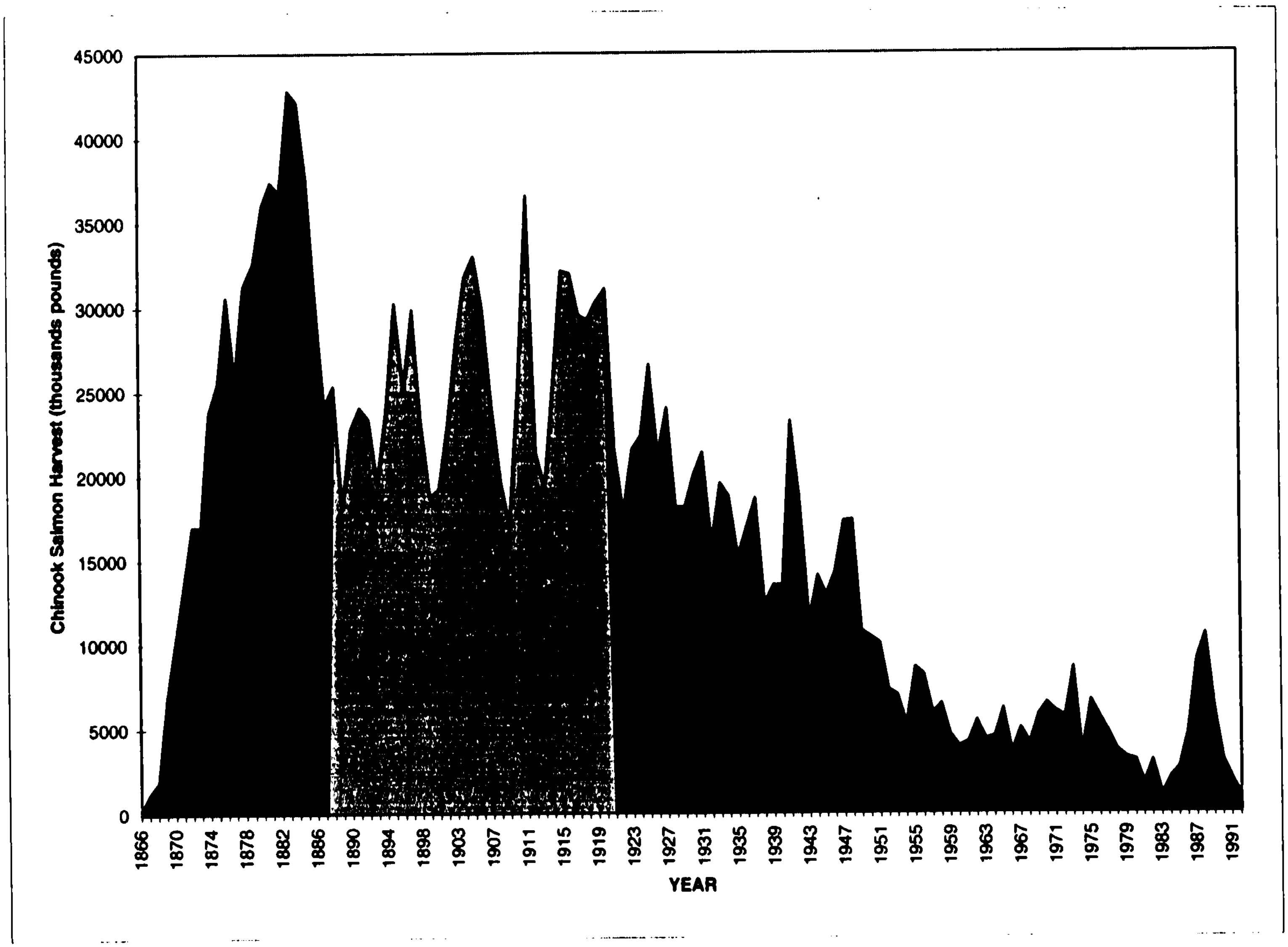

Figure 4. The annual harvest of chinook salmon in the Columbia Basin. The highlighted region (1889-1920) is discussed in the text. (*Source: Beiningen 1976: ODFW and WDF 1993*)

1887 and operated it for one year, then turned it over the U. S. Fish Commission. In 1901, the Oregon Fish Commissioner, Henry Van Deusen, lamented the lost hatchery production from 1882 to 1886 calling the closure premature and one of the biggest mistakes made by the industry (ODF 1900). He asserted that if the hatchery had remained open the total pack by 1901 would have increased to 800,000 cases. The actual pack in 1901 was 390,000 cases. The pack of chinook salmon in the Columbia River never did reached 800,000' cases at any time during the history of the canning industry.

The hatchery program increased rapidly after 1888 and maintained high levels of production through the end of the period in 1920 (Figure 5). After turning the Clackamas Hatchery over to the U. S. Fish Commission, the State of Oregon built a hatchery in a cannery at Warrendale in 1889. Several hatcheries were built in the lower river, and in 1901, salmon from the Snake and Grande Ronde rivers were artificially propagated (Cobb 1930). In 1909 Oregon constructed Central Hatchery (later named Bonneville Hatchery) on Tanner Creek in the lower river. Central Hatchery had the capacity to handle 60,000,000 eggs and served as a central clearinghouse and incubation station for eggs collected throughout the region (Wallis 1964). Eyed eggs and fry from the Central Hatchery were distributed in the Columbia Basin and beyond (Figure 6) and very often the source and final destination of the eggs and fry were not the same stream. For example. chinook salmon eggs from the Kalama River, Washington were stocked in the Alsea River, Oregon, and eggs from the McKenzie River, Oregon (Willamette Basin) were stocked into the Yaquina River on Oregon's coast (Wallis 1964).

Central Hatchery had another purpose: to circumvent the perceived high mortality of juveniles during their downstream migration. Fingerlings released in the lower river were closer to the ocean and, therefore, it was believed the juveniles would have lower mortality during their migration to the sea and return as adults in greater numbers (Wallis 1964).While Oregon's salmon managers believed large centralized incubation and rearing facilities were beneficial, those in Washington favored the construction of several smaller hatcheries and then only after a thorough investigation was completed (WDFG 1907).

Washington State entered into the artificial propagation of salmon cautiously by contributing $2,000 to the Oregon and Washington Fish Propagating Company's hatchery fund. After Washington State established a hatchery fund from the sale of fishing licenses, it built the Chinook River Hatchery in 1895. In ensuing years hatcheries were built in the lower as well as in the upper Columbia River.

Throughout this period, hatcheries were pursued with blind optimism based on the untested assumption that artificial propagation was more efficient than natural spawning and incubation of salmon eggs (Lichatowich and Nichola s***in press;*** Hedgepeth 1941; Smith 1919). Eggs were incubated in the hatchery and released either immediately after hatching or after the yolk sack had been absorbed. Early culturists assumed that this would prevent the "wastage" of naturally spawned eggs due to predators or natural events such as floods. The following excerpts illustrate the attitude towards artificial propagation during this period:

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[4] A case consisted of 48 one pound cans.

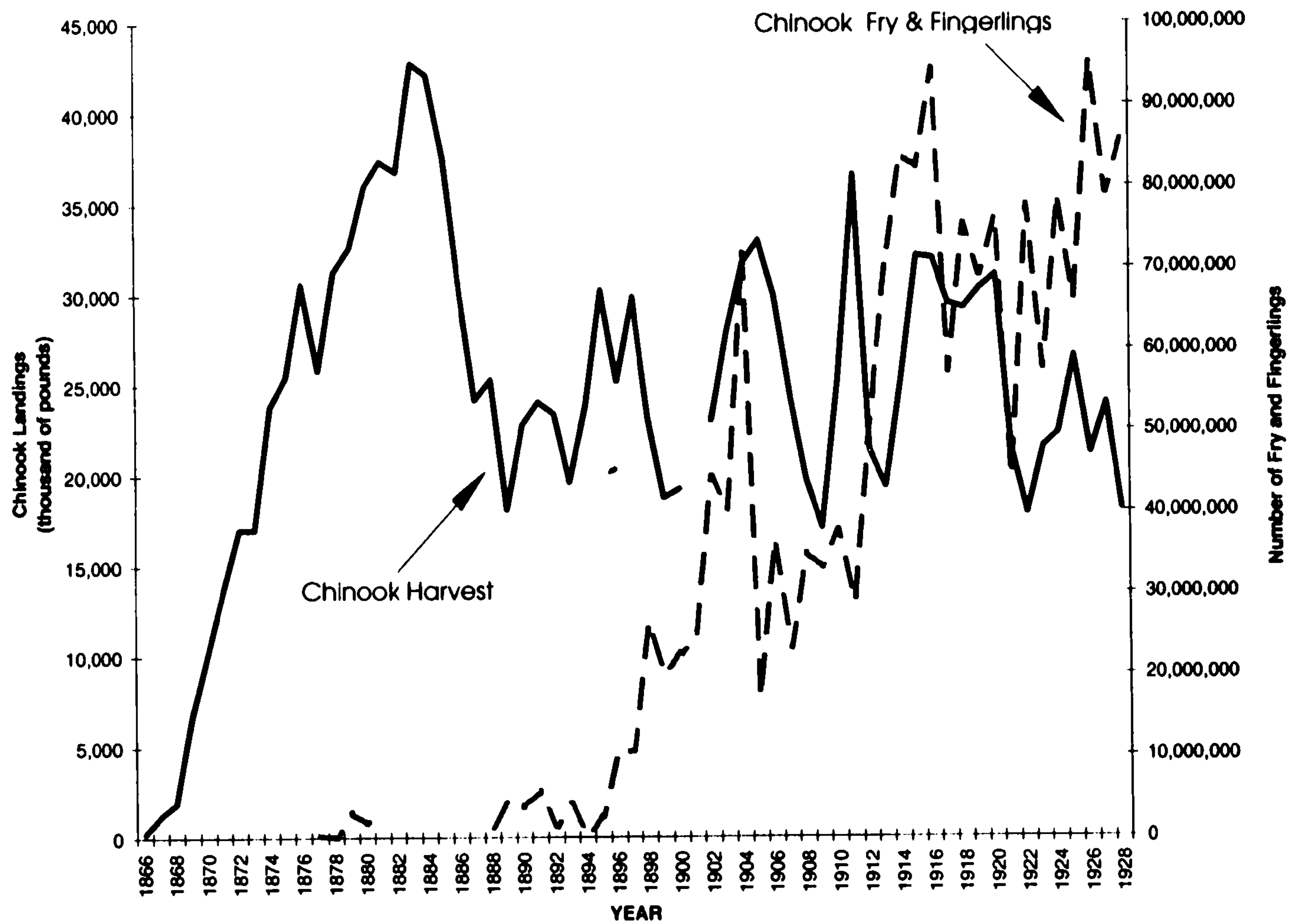

Figure 5. Harvest of chinook salmon and the release of chinook salmon fry and fingerlings from hatcheries in the Columbia Basin. (*Source: Beiningen 1976; Cobb 1930*)

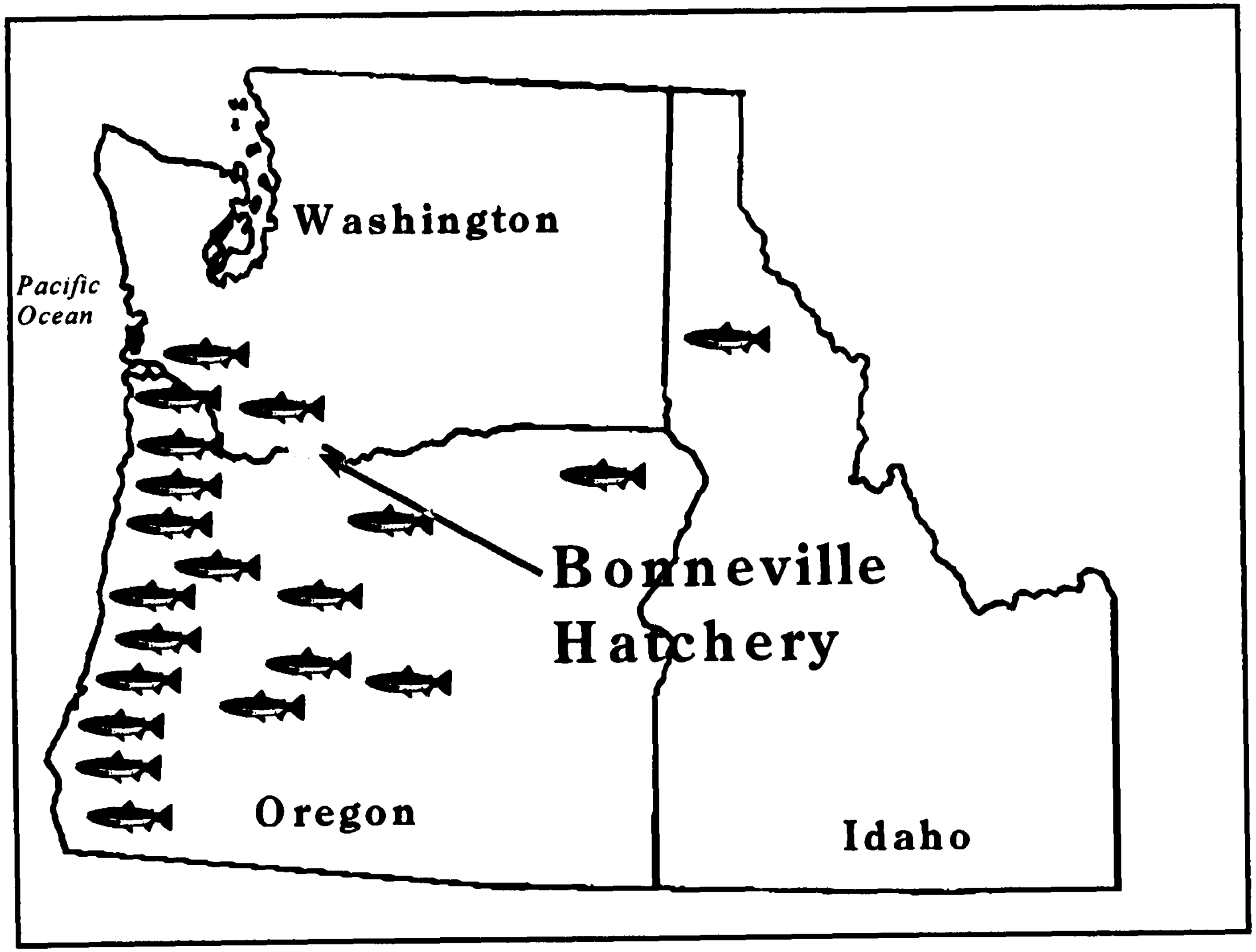

Figure 6. Transfers of chinook salmon from Bonneville Hatchery to other locations in Washington, Oregon and Idaho from 1909 to 1950. Each line can represent multiple plants. (*Source: Wallis 1964*)

> *"By the successful system of hatcheries the states of Oregon and Washington now maintain on the Columbia River, the permanency of the fishing industry of this state, in the Columbia River district is assuredfor all time to come: for it has been fully demonstrated the last two years that the art of artificial propagation has solved the problem of restocking the river with this most important product of our state's commerce. . . . I believe that with the system of hatcheries now maintained in the state, not only the present supply of fish can always be maintained, but with each succeeding year will come an increase. " (Pacific Coast Fisheries 1903 p. 5)*

> *"lt is imperative, therefore, that some means be adopted to counteract the depletions arising from this source (habitat degradation); but the most important reason for the artificial propagation is the fact that the natural method is extremely wasteful, which is not true of the artificial method. " (Smith 1919 p. 6)*

> *"In my opinion, if the salmon runs of this state are to be maintained and increased, it is going to be necessary to constantly construct new hatcheries. The much greater effectiveness of hatchery operations, as compared with natural propagation, has in my judgement been so effectively proven as to no longer permit discussions among those who are acquainted with the situation. " (WDFG* 1921 ***p. 17)***

> ***"There can be no doubt in the mind of anyone who has studied the question. that the future prosperity of our salmon fisheries depend largely upon artificial propagation... I am convinced that not more than IO percent of the ova spawned in the open streams are hatched, owing principally to spawn-eating fish that prey on them... while from artificial propagation 90 percent are successfully hatched. What more need be said in favor of fish culture?" (Oregon State Fish and Game Protector 1896 p. 33)***

Carrying capacity or a natural limitation in production was not a part of the conceptual framework that justified the use of artificial propagation. Managers apparently believed that saving incubating eggs from their natural enemies would release them from constraints and total production would increase. However, the increase in production actually achieved through artificial propagation was not measured. The belief in hatcheries was so strong that their benefits were taken on faith (Chamberlain 1903). Repeatedly during this period the success of hatcheries was proclaimed and those who might disagree were dismissed as being uninformed, although the managers collected little information with which to become informed. For example, as stated earlier, George Brown Goode of the U. S. Fish Commission declared that the salmon industry on the west coast was thoroughly under the control of fish culture (Maitland 1884). He made that statement in 1883 when there were only two hatcheries operating on the entire west coast. His statement required either tremendous faith and optimism or tremendous cynicism. This kind of unfounded statement was not typical of the careful scientific work of the U. S. Fisheries Commission in other areas such as descriptive zoology and fish distribution. Perhaps a major reason for the lack of scientific rigor where artificial propagation was concerned was the political cynicism and deception that was part of the early program. Many plants of hatchery fish were made to curry political favor regardless of the biological appropriateness of the action. For example, in response to a warning that some salmon eggs were not being wisely distributed Spencer Baird replied:

> ***"It does not make much difference what [is done] with the salmon eggs. The object is to introduce them into as many streams as possible and have credit with Congress accordingly. If they are there, they are there, and we can so swear, and that is the end of it." (Letter from Spencer Baird to Charles Atkins 16 November 1877 cited in Allard I978 p. 160).***

The political cynicism came full circle when George Brown Goode used as a measure of success of artificial propagation Congress's continued financial support for the program (Maitland 1884). Using hatcheries for political expediency virtually guaranteed the program would not receive critical evaluation. Although parts of the hatchery programs have been evaluated in recent years (e.g. Wahle and Vreeland 1978; Wahle et al. 1974; Vreeland 1989), there has never been a comprehensive evaluation of the hatchery programs in the Columbia River even though it has been a major management tool for 120 years.

Marshall McDonald, who succeeded Spencer Baird in 1887 as United States Commissioner of Fish and Fisheries, had a different attitude toward artificial propagation which he described in his opening address to the 1893 World Fisheries Congress:

> ***'I am disposed to think that in this country we have relied too exclusively upon artificial propagation as a sole and adequate means for the maintenance of our fisheries. The artificial impregnation and hatching of fish ova and the planting of fry have been conducted on a stupendous scale. We have been disposed to measure results by quantity rather than quality, to estimate triumphs by volume rather than by potentiality. We have paid too little attention to the necessary conditions to be fulfilled in order to give the largest return for a given expenditure of effort and money." (McDonald 1894 p. 15)***

McDonald went on to state that harvest regulation is a necessary component of management even when artificial propagation is practiced (McDonald 1894).

When McDonald made his remarks, four million salmon fry were being released from hatcheries in the Columbia Basin and his words did little to dampen the enthusiasm for hatcheries. Artificial propagation in the basin increased dramatically after 1896 as the states deepened their commitment to salmon culture. By 1908, 34 million fry were being released into the Columbia River each year (Cobb 1930) however, given the increase in the level of artificial propagation the Oregon Fish Commissioners were alarmed at the continuing decline in the spring chinook salmon and the need to harvest more of the inferior fall runs of chinook and coho salmon to supply the canneries. By 1908, managers were beginning to realize that the sack fry released from their hatcheries were also vulnerable to predation by trout and other species so they began experimenting with extended rearing programs.

Declining catches in spite of the intensity of artificial propagation began to discourage fishery managers (Oregon Department of Fisheries (ODF) 1908) and led to a series of formal experiments initiated in 1910. With advice and financial assistance from several of the cannery operators, state hatcheries began rearing juvenile salmon and releasing them at larger sizes. Coincident with this experiment, the catch increased in 19 14; and after five successive years of improved catches in the Columbia River, the Oregon Fish and Game Commission (OFGC) announced the success of its experiments:

> ***"...this improved method has now passed the experimental stage, and ...the Columbia River as a salmon producer has 'come back ' By following the present system, and adding to the capacity of our hatcheries. thereby increasing the output of young fish. there is no reason to doubt but that the annual pack can in time be built up to greater numbers than ever before known in the history of the industry... ' (OFGC 191 9 p. 16).***

The increase in the size of the run in 19 14 seemed to be a wide spread phenomena in the basin that was observed in tributaries without hatcheries. Van Cleve and Ting (1960) noted that the largest run in the memory of white people entered the Umatilla River in 1914. Both Indians and non-Indians caught thousands of salmon from spring through fall in that year. Recent review of the information has disputed the conclusion that the increased catch was caused by the new methodology (Johnson 1984).

As this period came to a close, professional biologists began raising doubts about the ability of hatcheries to maintain commercial food fish fisheries. This statement appeared in the Report of the U. S. Fish Commission for 1923 and reflected the growing attitude of fishery professionals:

> ***"The correction of existing and the prevention of prospective depletion has been sought principally through the agency of fish culture and legislation more or less restrictive of fishing operations and practice. It is obvious that a foundation for these measures must be established on an accurate and reasonably complete knowledge of the life histories of the organisms with which they deal, as otherwise they may prove wasteful and ineffective while at the same time imposing futile obstacles to the development of a legitimate and essential industry. " (cited in*** wood 1953).

Biologists were beginning to realize that a failure to implement Objective 1 of the culture program (see page 8) had been a mistake whose consequence was depleted fish populations. Herschel Whitaker (18%) reminded his fellow professionals that they could not sit back and continue to plant fish in bodies of water where the fisheries were abusive and uncontrolled. In fact, he believed fish culturists had a moral obligation as citizens not to waste money in futile efforts using hatcheries to plant fish into rivers and lakes where no benefits could be expected. It was becoming clear to at least some fisheries professionals that the successful planting of hatchery fish required more knowledge of the fishes' ecology and the environment of the planted waters than was currently the norm (Brown 1922). However, most of the concerns came from biologists working in the eastern part of the country. In the Columbia River, the salmon were not increasing in abundance even though the hatcheries were still releasing large numbers of fry. As long as the artificial propagation programs were not scientifically evaluated, the proponents of hatcheries could claim responsibility for the robust wild salmon stocks that still returned to the river.

2. Harvest

From 1889 to 1920 the harvest of chinook salmon fluctuated around a average of about 25 million pounds (Lichatowich and Mobrand 1995). Although the harvest of chinook salmon was variable, it did not show an obvious increasing or decreasing trend over the entire period. However, catch data alone fails to reveal significant qualitative changes in the basin's chinook salmon and the fishery. Harvest was rapidly shifting from the prime spring and summer chinook salmon to the fall run fish which were considered of lower quality for canning purposes (Craig and Hacker 1940; DeLoach 1939). The spring run, which in 1883, produced a catch of 43 million pounds (Columbia River Fisheries Interim Investigation Committee (CRFIIC) 1943), had declined by 1919 to a small part of the total harvest (Figure 7). Spring and summer runs of chinook salmon continued to decline through this period and beyond. In addition to a shift to fall run chinook salmon, in 1889, the first sockeye salmon were harvested and canned, and in 1892 the fishery started targeting coho salmon (Craig and Hacker 1940).

Although habitat problems, particularly those associated with irrigation and logging were recognized (OBFC 1890; WDFG 19 11) as responsible for part of the decline, the intensive fishery conducted from The Dalles to the mouth of the river was considered the biggest cause of depletion (McDonald 1895).

Significant changes were taking place in canning technology which in turn influenced the fishery. The "iron chink" butchering machine, the sanitary can and double seamer which eliminated the hand soldering were among the inventions that produced the modem high speed cannery lines. Improved efficiency stimulated greater demand for more fish. For example, in 1877, average production ranged from 240B450 cases a day with crews of 130 to 300 persons, but by 1883 average daily production rose to 1,000 cases a day with crews of 120 to 140 persons (Stacey 1982).

The fishery was also making significant changes. Part of the change was simply the addition of more gear. The number of gill nets increased from 900 in 1880 to 2,200 in 1894, traps increased from 20 in 188 1 to 378 in 1895 and fish wheels went from 1 in 1882 to 57 in 1895 (Smith 1979). As important as these increases in fishing power were, another technological change would eventually eclipse and outlast them.

In 1898, F. J. Larkin moved to Portland from San Francisco and he brought with him an idea which would revolutionize the salmon fishery. Larkin wanted to place a gasoline engine in each of the gill net boats operating in the lower Columbia River. Nine years later, half of the boats operating out of Astoria were equipped with engines and the number was rapidly increasing (Pacific Fisherman 1906, 1958). Power from gasoline engines increased the effectiveness of the traditional gillnetter operating in the lower river, however, the gasoline engine also gave rise to the troll fishery which dramatically changed the harvest and created a set of biological and international problems that have persisted through to the present. From a small beginning in 1912, the troll fleet grew to about 2,000 boats by 1920. It was recognized early that the trollers were harvesting immature salmon and in doing so preventing the harvest of the larger, mature fish in the river with the loss of significant poundage (Smith 1920).

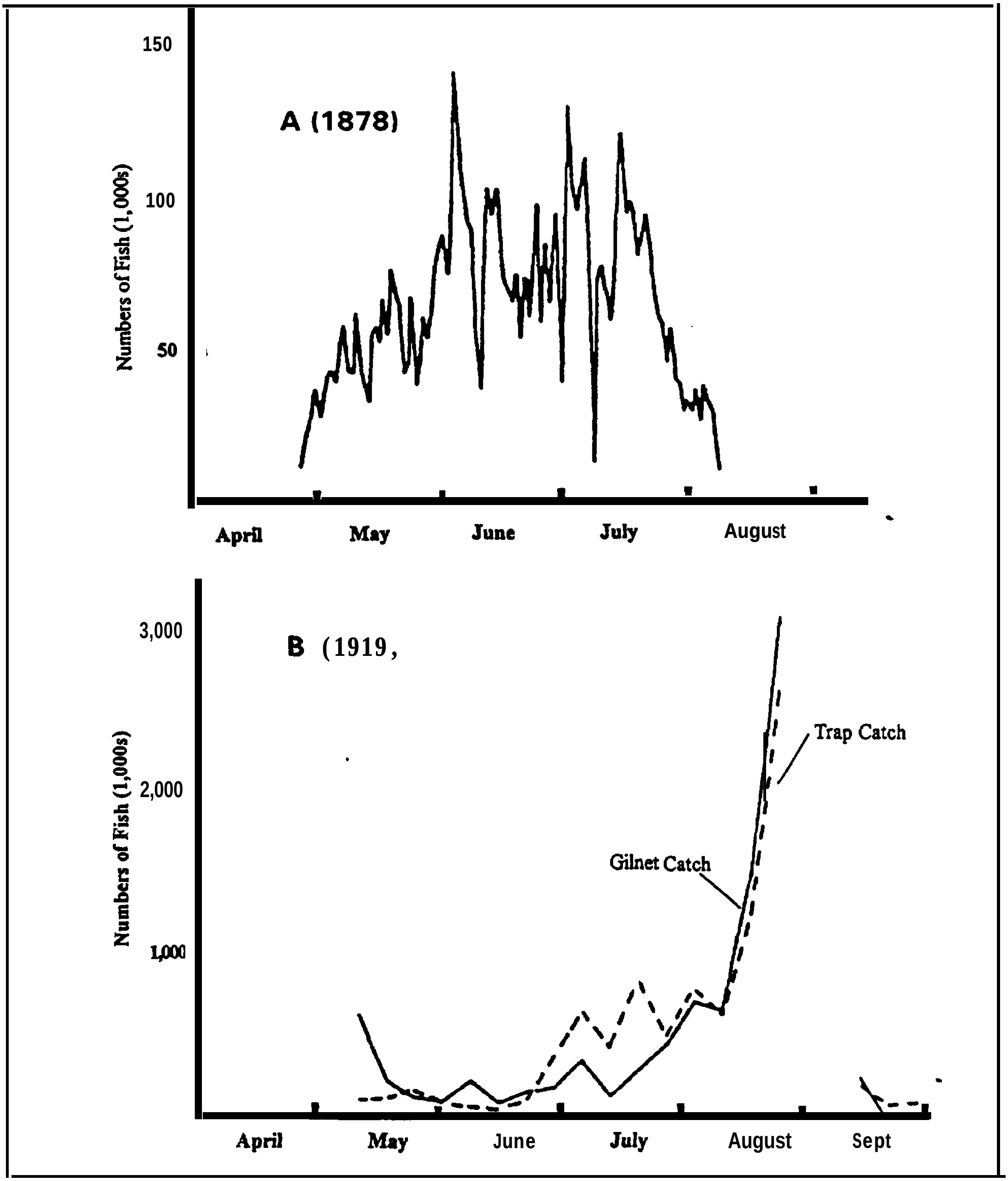

Figure 7. Comparison of the seasonal distribution of the chinook harvest in the Columbia River in 1878 (A) and 1919 (B). (Source: Whitney and *White 1984*)

Prior to 1909, fishing regulations were promulgated by the states of Oregon and Washington independently of each other which often led to different regulations on each side of the river. In 1908, the two states began meeting annually to set concurrent regulations. Cooperative harvest regulation eventually led to congressional approval of an interstate compact in 19 18. The compact stipulated that changes in fishing regulations could only be made by mutual consent of the two states. From 1908 to 1936 fishing in the Columbia River was closed during the months of March and April and from August 25 to September 10. During the period of open fishing there were additional weekend closures (Wendler 1966).

3. Habitat

Habitat in the basin during this period underwent significant deterioration. Habitat degradation started in the previous period continued, however, mechanization probably accelerated the rate. Logging, gold mining, grazing, irrigation and small hydropower developments were the principal causes of habitat degradation (Lichatowich and Mobrand 1995; Wissmar et al. 1994). At the end of this period, irrigation ditches, which were largely unscreened, caused the loss of millions of juvenile salmon and reduced natural stream flows. Irrigation diversions were probably the greatest destroyers of salmon habitat and productivity, especially east of the Cascade Mountains.

Salmon were killed when they entered unscreened irrigation diversions and were deposited in cultivated fields and pastures. A study carried out in the Yakima River in 19 16 estimated that 4.5 million migrating salmon were killed with each watering of the irrigated lands in the basin (Pacific Fisherman 1920). Low flows below irrigation diversions and inadequate ladders at diversion dams blocked migration of juvenile and adult salmon. The loss of natural stream flow degraded habitat quality and further reduced production and productivity of the salmon. Reduced flows due to irrigation combined with the changes in riparian cover and channel morphology' to elevate temperatures beyond the tolerances of salmon especially east of the Cascade Range (Lichatowich and Mobrand 1995). Irrigation, livestock grazing and mining were major contributors to cumulative degradation of salmon habitat before 19 10 and afterwards timber harvest, fire management, as well as irrigation assumed more importance (Wissmar et al. 1994). The construction of dams in the tributaries was also an important source of habitat degradation and the loss of access to parts of the basin. Large portions of the upper Columbia Basin were lost to salmon production during this period due to dams in the tributaries. Prior to 1920,27 major dams had been built in the basin (Table 1).

C. MANAGEMENT FRAMEWORK

1889 to 1920 was a period of transition in the management of the Pacific salmon fisheries in the Columbia Basin. The basic approach to resource management was shifting from the laissez-faire policies toward harvest and a reliance on hatcheries to the new concept of conservation which was part of the Progressive movement (Hayes 1959). To the Progressives, conservation of natural resources meant efficient management by government experts to give the greatest good for the greatest number of people over the long run. The Progressives, including their most

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[5] Grazing, mining or lumber harvest removed riparian cover and made stream channels broader and shallower.

Table 1. **Partial list of dams constructed in the Columbia Basin 1889-1920. (Source:** Lavier **1976)**

Dams	River	Height (ft.)	Date
Arrowrock	Boise	253	1915
Bull Run	Sandy		1912
Bumping	Bumping	45	1910
Cazadero	Clackamas	60	1904
Zonconully	okanogan		1916
Condit	Big White Salmon	125	1913
Dryden	Wenatchee		1908
Washington Water Power Co.	Clear-water		1908
Kachess	Kachess .	63	1912
Keechelus	Yakima	70	1917
Little Falls	Spokane	60-70	1909
Long Lake	Spokane		1915
Lower Salmon	Snake	88	1910
Nine Mile Falls	Spokane	60	1909
River Mill	Clackamas	110	1910
Sunnyside	Yakima	8	1907
Sunbeam	Salmon		1913
Swan Falls	Snake	30	1910
Tumwater	Wenatchee	23	1905
Wapato	Yakima	9	1917
Warm Springs	Malheui		1919
Washington Water Power Co.	Methow		1915
Willow Creek	Malheur	100	1912

prominent spokesmen Theodore Roosevelt and Gifford Pinchot, believed that conservation meant wise use (McEvoy 1986). Nature was still believed to be there to serve man, but the Progressives believed that man in turn had an obligation to develop and use those resources wisely. This translated into management according to scientific principles (Meine 1988). During this same time, individuals like John Muir advocated less utilitarian approaches to conservation. However, the dominant view promoted maximum efficiency and highest use with the emphasis on use. Resource management for nonextractive or noneconomic purposes was not considered as part of good conservation. Wilderness areas, for example, were not set aside in the national forests until after 1920 (Meine 1988; Williams 1989).

Fishery biologists recognized the emergence of two new concepts of conservation - a preservationist and a progressive one (Townsend 1911). Both views were expressed in their literature. In 19 10, the president of the American Fisheries Society (AFS) supported the Progressive's interpretation of conservation while recognizing that many of the members of AFS considered this view treason. The Progressive principle of highest use made the loss of trout streams acceptable where other uses such as timber harvest or agriculture had greater value. However, trout streams that were more productive than the surrounding land, could be protected (Bower 1911). Others argued for the establishment of fish refuges to preserve native fish fauna, including the "little fishes" of noncommercial value (Ward 1913). In the Columbia River, where the fishery was a major economic power, the utilitarian view of the Progressives held sway.

Efficient management for the greatest good required information, and during the later decades of this period, fishery scientists began systematically collecting information on the biology of the Pacific salmon. Gilbert (1913) established the basic life histories of the Pacific salmon through the analysis of circuli patterns on scales. In 1914, Gilbert's student, Willis Rich, began collecting juvenile chinook salmon in the lower Columbia River to advance the understanding of life histories and apply that knowledge to the improvement of hatchery practices. Rich (1920) observed an extended migration of subyearling chinook salmon through the lower river. He believed this was the result of successive waves of migrants from individual basins, each with a different migration pattern. Rich undertook additional studies of the life history and biology of chinook salmon (Rich 1927; Rich and Holmes 1929) which probably contributed to and reinforced his belief that the watershed should be the unit of study (International Pacific Salmon Investigation Federation (IPSTF) 1925). This recommendation was lost until its recent rediscovery as part of the ecosystem approach to management.

The information collected by the scientists such as Gilbert, Rich and others eventually led to an improved basic understanding of the salmon's biology in the next period (after 1920). The improved understanding had minimal impact on the framework, however. Prior to the initial investigations, management was based on a body of scientific theories and cultural beliefs which comprised a management framework that, with the benefit of hindsight, was not very useful. For example, as discussed earlier, biologists theorized that the relative strength of the seasonal components of the annual spawning migration of chinook salmon was determined by the spring freshet. A good snow pack and large freshet would attract more of the maturing fish into the river in the spring and summer leaving fewer fish for the fall migration (Jordan and Gilbert 1887). A small spring freshet had the opposite effect. Biologists also believed that after leaving the river, juvenile salmon reared in the ocean within a few miles of its mouth until they matured (Jordan 1904). Another part of the framework was the assumption that salmon eggs buried in the gravel of natural rivers suffered high mortality from predation or floods and that this mortality could be circumvented by incubating eggs in a hatchery and releasing the sack fry - i.e., capacity and productivity of the ecosystem could be increased by protecting salmon eggs during incubation.

This conceptual view of the chinook salmon led to a specific set of management prescriptions. Since it was believed that run timing (spring, summer and fall) was a response to the river environment and not an inherited trait, it was not critical to protect the prime, spring migrating fish. An adequate escapement of the fall run salmon would also protect the spring migrating fish and hatcheries that took eggs from fall run fish would, under the ideal flow conditions, enhance the spring migration of chinook salmon (Pacific Fisherman 1904). This theory had its detractors and was subject to debate (Pacific Fisherman 1903), however, harvest and hatcheries were generally managed to maximize protection and artificial propagation of the fall run while concentrating harvest on the spring run.

The homing of salmon back to the stream of their birth - the home stream theory - was debated until the late 1930s. At the turn of the century experts such as David Starr Jordan did not accept the home stream theory (Jordan 1904). He argued that salmon, while in the ocean, never migrated more than 20 to 40 miles from the mouth of their home river. When mature, the adult salmon simply entered the first river they came to, usually their home stream. In 1896, chinook salmon fry released from Clackamas Hatchery were marked with an adipose clip and returns were recorded in 1898, 1899 and 1900. Most of the marked fish were recovered in the Columbia River, however, a few were recovered in the Sacramento River - the eggs for this group of marked chinook salmon came from the Sacramento River. Jordan interpreted these data as supporting his theory that the salmon did not have a special ability to home back to their natal stream. When the salmon matured they simply entered the first river they encountered which, because they did not migrate very far, would generally be the river of their birth. Jordan concluded, the results of the marking experiments did not support the home stream theory, but it did support his theory of a limited ocean migration (Jordan 1904). Jordan's interpretation of the results of the marking experiment is an example of the power of the framework to influence the interpretation of information and observation.

There was a general belief that salmon were genetically uniform (Ricker 1972) which was consistent with the operation of the basin's hatcheries, For example, Central Hatchery (Bonneville) was built and operated in a way that was consistent with a uniform genetic structure of the species of Pacific salmon.

Theories regarding the seasonal migration, homing or lack of it and genetic structure of species illustrate the power and importance of the conceptual framework. The results of the marking experiments could have been interpreted as supporting the home stream theory. However, because Jordan's framework included an erroneous theory the data were misinterpreted. Faulty theories clearly led to a management framework and policies that were detrimental to the conservation of the resource, especially the spring run chinook salmon. They also led to hatchery operations that were detrimental to reproductive isolation and stock structure of the chinook salmon.

The theories in aggregate, comprised a management framework that supported the prevailing social beliefs, in particular, the excessive exploitation of the salmon. It is not clear whether the scientific theories were independent of the social environment or were responding to it (e.g., Bottom in press). It is clear, however, that the conceptual view of the salmon's biology and the resulting management framework led to erroneous interpretation of information and counterproductive management prescriptions.

The reports of this period exhibit two conflicting attitudes toward the Columbia's salmon resources and its industry: an apprehension regarding the future of the salmon fishery (e.g., Hume 1893; McDonald 1895) and an unrestrained optimism that hatcheries would reverse the declines (e.g., OFGC 1919; WDFG 1904). The financial commitment to artificial propagation underscores the confidence in hatcheries. In Oregon, the expenditures for artificial propagation in fiscal year 1922 consumed 76 percent of total expenses of the Fish Commission (Shoemaker and Clanton 1923). A review of the annual reports of the management institutions shows repeatedly that an increase in the cannery pack from one year to the next was attributed to the effects of hatcheries (e.g., ODF 1907; OFGC 1919; WDFG 1917) rather than natural variability which we now know was the cause. The selling of hatchery programs as the solution to declining runs and the large financial investment in their operation caused the managers to look for every opportunity to claim success and prove the wisdom of their expenditures. However, there was no hard evidence to support the claims of success.

Artificial propagation easily made the transition to the Progressives vision of conservation, and it could be argued that hatcheries were preadapted to lead the way for the adoption of Progressive ideas in fisheries. Hatcheries were portrayed as efficient, scientific means of ensuring maximum utilization of a watershed. The artificial propagation of salmon gave the appearance of the efficiency of the centralized production of a factory. However, the states of Oregon and Washington used different approaches to achieve production efficiency. Oregon favored the centralized control over production exemplified by Central Hatchery. Washington State believed it was inefficient to ship eggs into a central hatchery. Instead, it favored locating several hatcheries on different rivers (WDFG 1907). Hatcheries made it possible to irrigate crops, graze cattle, harvest trees, generate electricity and still maintain the salmon cannery industry. Hatcheries permitted the "highest use" of the watershed. The management framework which supported the use of artificial propagation appeared to be based on the assumption that there is a simple relationship between the number of fry released into the river and the supply of adult fish to the fishery. Enhancing salmon productivity was simply a matter of circumventing mortality during their early life stages. From this model, it naturally followed that hatcheries need only be evaluated in terms of fry released.

Managers were aware that the spring run of chinook salmon was disappearing and harvest levels were being maintained by a shift to the inferior fall run chinook or other species. That knowledge was not translated into action, in part, because of false theories of salmon biology, an over reliance on hatcheries and their influence in the management framework. Management was consistent with the prevailing social and economic ideals of the Progressives.

D. SUMMARY

<u>Status</u> Total harvest of chinook salmon was relatively stable and achieved an annual average harvest of 25 million pounds. The fishery intensified with a significant depletion of adult spawners in the upper basin. The spring run declined and total catch had to be maintained by harvesting more of the fall run fish, which cannery operators considered inferior.

<u>Response</u> Salmon managers maintained their belief that artificial propagation could overcome the effects of excessive harvest and habitat degradation. Irrigation, mining, grazing and timber harvest were rapidly degrading the quality of salmon habitat. Harvest restrictions were still minimal, but after 1908, Oregon and Washington enacted uniform harvest regulations.

<u>Management Framework</u> Justification for a strong reliance on artificial propagation shifted from the religious-based mandate that man should control nature to the Progressive vision of conservation: Natural resources should be managed for maximum economic efficiency by technical experts. Hatcheries easily made the transition to this new set of values. The basic assumption that humans can and should simplify and control salmon production was retained.

IV. 1921 TO 1958

A. STATUS OVERVIEW

The harvest of chinook salmon in the Columbia River declined dramatically during this period (Figure 8). Part of the apparent decline was due to the expansion of the troll fishery which harvested chinook salmon from the Columbia River in the ocean and landed the fish in ports from Alaska to California. Salmon from the Columbia River landed in distant ports are not included in the harvest data shown in Figure 8. Even when the additional catch of the troll fishery is considered, the chinook salmon from the Columbia River was in decline (Silliman 1948).

In 1925, tagging and release of ocean-caught chinook salmon by biologists in British Columbia showed that chinook salmon from the Columbia River made a major contribution to the troll fishery off the west coast of Vancouver Island. Fall chinook made the largest contribution to the British Columbia troll harvest; few spring run fish were caught (Milne 1957). Depletion of the spring run prior to 1925 as well as different migration patterns might explain the difference in contribution of spring and fall run fish to the British Columbia troll fishery.

In 1883,43 million pounds of chinook salmon were harvested from the spring run alone (CRFIIC 1943) and by 1958, the total in-river harvest of all species of salmon amounted to 8.1 million pounds (Beiningen 1976). Between 1938 and 1947, the harvest of chinook salmon from the Columbia River including an estimate of the troll catch averaged 2 1 million pounds (Laythe 1948), or about half the harvest in 1883. The number of operating canneries dropped from 22 in 1920 to 7 in 1958.

All the salmon fisheries south of British Columbia peaked before the close of the last period (1889- 1920)(Table 2) and the subsequent persistent declines especially after 1920 prompted several attempts to develop cooperative programs of salmon research, restoration and management. Those efforts produced little tangible progress until the massive hydroelectric development of the mainstems of the Columbia and Snake rivers produced the Lower Columbia River Fisheries Development Program (LCRFDP) (Laythe 1948). Some attempts to improve the management of the salmon fishery such as the Pacific Salmon Investigation Federation, recognized the need for more scientific information to guide management. On the other hand the LCRFDP gave research a low priority (PNWFC 1950) and basically continued the policies of the past with strong emphasis on artificial propagation. Four of the attempts to improve salmon management and research are described in more detail below.

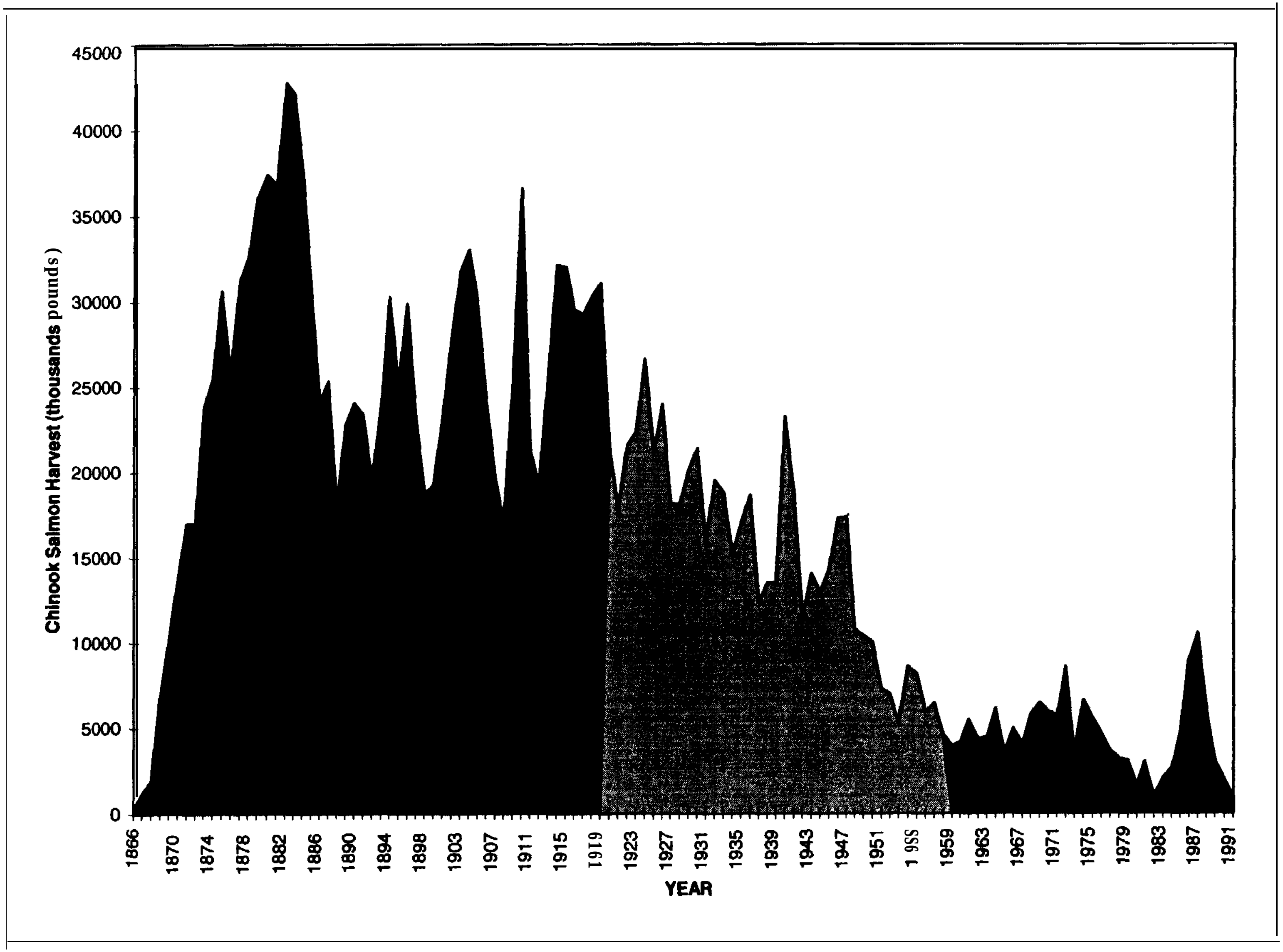

Figure 8. The annual harvest of chinook salmon in the Columbia Basin. The highlighted region (921- 958) is discussed in the text (*Source: Beiningen 1976 ; ODFW and WDF 1993*)

Table 2. **The year that salmon harvests peaked at various locations in the Pacific Northwest. (Source: Cobb 1930)**

Location	*Year*
Sacramento River	1882
Columbia River	1895
Coastal Oregon	1911
Grays Harbor	1911
Kalamath	1912
Puget Sound	1913
Coastal Washington	1915

1. International Pacific Salmon Investigation Federation

On March 16 and 17, 1925, the Washington State Fisheries Board hosted a meeting of leaders in salmon management from the Dominion of Canada, the Province of British Columbia, the United States Government, and the states of Alaska, California, Oregon and Washington. The purpose of the meeting was to establish an organization that would facilitate the exchange and coordination of information among regional research and management institutions, and provide a forum for discussing mutual problems. The organizers of the meeting wanted to increase the efficiency of efforts to perpetuate and build up the Pacific salmon fisheries. The executives of management institutions realized:

> ***"...that present efforts to preserve the salmon fisheries, whether through regulation of fishing, hatchery operations, or other means, are without any adequate basis of accurate knowledge of the underlying facts; and further, that the efforts to get at such facts, as conducted in the past have been scattered, unorganized, and therefore less effective than they should be. . . . it was admitted by all, that efforts at conservation are merely groping in the dark." (IPSIF 1925 p. 5)***

The first meeting discussed approaches to major problems facing salmon mangers: Control of fishing beyond the three mile limit; the need for uniform statistics on the salmon fishery; and the need for comprehensive information on the biology and life history of salmon. Willis Rich told the Federation that their efforts needed to be organized and directed by a program comprised of two parts. He recognized a need to identify immediate objectives and specific activities to achieve them. Short-term projects and objectives would change from time to time, but Rich also pointed out the need to define a longer term and broader program, carefully designed to provide a framework upon which the short-term projects could be hung. Rich apparently was calling for the development of an explicit management framework which would provide the theoretical foundation for selecting specific projects and interpreting the information generated by them. Rich also identified the watershed as the basic management unit for Pacific salmon (IPSIF 1925). The organization apparently ceased to exist after 1929.

2. The Oregon State Planning Board

In 1938, the governor of Oregon asked the Oregon State Planning Board (OSPB) to study the commercial salmon fishery. The original objective of the study was to determine the need to regulate or terminate the use of specific types of fishing gear. The board recognized that there was an immediate need for aggressive action and close coordination among the federal and state agencies including Oregon, Washington, Idaho and California Action and coordination were needed to effectively regulate the fishery and preserve the spawning grounds. The board recommended that the legislatures in the states of Oregon, Washington and Idaho enact an interstate compact which would establish a joint Columbia River Fisheries Commission with ex-officio participation by the federal fisheries agencies. The new fisheries commission would regulate the total catch to achieve adequate escapement, set the seasons, prescribe the types of fishing gear and direct the needed scientific investigations. Proposed research included the effect of pollution on salmon production; improvement in fish cultural operations; a study of the effects of heavy exploitation of the sardine and other food fishes of the salmon, and a study of the need to set aside tributaries to be preserved as salmon refuges (OSPB 1938). It appears the board's recommendations were influenced by the terms of the International Pacific Salmon Fisheries Commission which had been ratified by Canada and the United States in July 1937. The OSPB recommendations were not implemented.

3. Washington State Senate Joint Resolution No. 13

In 1941, three years after the OSPB completed its report, the Washington State Senate under the authority of Senate Joint Resolution No. 13 recognized that the 1918 compact with the State of Oregon was not preventing depletion of the salmon. The senate established a Columbia River Fisheries Interim Investigation Committee (CRFIIC) and instructed it to establish the existing status of the Columbia River fishery and make recommendations for legislation. The Washington committee was directed to work with similar committees in Idaho and Oregon.

The committee concluded there were three major causes for the decline of salmon and steelhead in the Columbia Basin (CRFIIC 1943):

> Overfishing   The CRFIIC recognized that the spring run of chinook salmon was depleted compared to 1883, but the committee believed the remaining spring run was adequately protected (in 1941). The summer run was being harvested at the 90 percent rate which was excessive. The CRFIIC felt a 15 day closed season was adequate to protect the fall chinook run. Idaho harvested salmon on their spawning grounds and some arrangement had to be made to trade a larger steelhead escapement to Idaho for protection of the spawning chinook salmon. The committee also indicated that the Indian fishery was a major cause of overharvest.

Habitat The most important problem was the loss of available spawning area above Bonneville Dam. In its survey of the basin, the CRFIIC found only one stream not heavily impacted by irrigation withdrawals and unladdered dams and that subbasin was the Salmon River in Idaho. They noted, however, that the Salmon River had habitat problems created by a dam which blocked sockeye migration into Redfish Lakes and from mining pollution and irrigation in some tributaries. The major production areas for summer and fall run chinook salmon were the remaining undammed mainstem areas of the Columbia and Snake rivers.

Institutional Problems The CRFIIC identified a lack of unified control over the fishery and regulatory inflexibility as a major problem. Oregon and Washington managed the intense fisheries in the lower river. Oregon's regulatory process was cumbersome, including the need to obtain legislative approval for regulation changes whereas regulatory authority in Washington was vested in the Director of the Department of Fisheries. Habitat protection laws were administered by four agencies and hatcheries supervised by three agencies. The committee concluded that "We are hopelessly defeated in obtaining any solution to the Columbia River fisheries unless we simplify our administration over the resource," (CRFIIC 1943 p. 7)

The CRFIIC and the OSPB made a similar recommendation, namely, the establishment of a tri-state fisheries commission with an independent staff to manage all aspects of the salmon fishery. The senate committee also recommended that the mandate of International Pacific Salmon Fisheries Commission be expanded to include management of the ocean fisheries in waters between the Oregon-California border and the boundary between Alaska and British Columbia (CRFIIC 1943). The CRFIIC recommendations were not implemented.

4. Lower Columbia River Fisheries Development Program

In the mid- 194Os, the fisheries agencies faced the prospects of a massive development of the hydroelectric potential of the Columbia Basin and to protect the salmon fishery they devised a plan to mitigate the impacts of the proposed development - the Lower Columbia River Fisheries Development Program (LCRFDP) which was modeled after the Grand Coulee salvage program.

The completion of Grand Coulee Dam in 194 1 permanently cut off 1,140 miles of spawning and rearing habitat for Pacific salmon (Fish and Hanavan 1948). Salmon production above Grand Coulee Dam was salvaged through hatchery mitigation and the relocation of stocks from above the dam to tributaries below Grand Coulee such as the Wenatchee, Entiat, Methow and Okanagon. The program was initiated in 1938 and by 1948, Fish and Hanavan (1948) concluded the program was a success. Later reviews gave mixed assessments. Ricker (1972) found little evidence for success, however, Mullan (1987) seemed to rate the program a qualified success in that it maintained genetic diversity of chinook salmon to some unknown degree. By the time fishery agencies were asked to develop a mitigation plan for the massive development that began after World War II, the Grand Coulee salvage program had five years of data to measure the effect of the salvage program against a five year baseline period (1938 to 1942 compared to 1943 to 1947) (Fish and Hanavan 1948). Statistically this kind of comparison using data collected over ten years was marginal at best (e.g., Lichatowich and Cramer 1979). When the LCRFDP was developed, rightly or wrongly the Grand Coulee Salvage Program was considered a success and it served as a model.

The LCRFDP was a cooperative program which included the states of Oregon and Washington and the U. S. Fish and Wildlife Service (USFWS). It had a planned life of 10 years, but it has continued for the past 45 years and it can be considered the grandfather of the current efforts to mitigate for the effects of the hydropower system (e.g. the Northwest Power Planning Council’s (NPPC) Fish and Wildlife Program). As the title suggests the program’s objective was to concentrate salmon production in the lower Columbia River below the proposed McNary Dam. At the time, biologists believed that the construction of the proposed dams in the mid and upper Columbia and Snake rivers would eventually eliminate or drastically reduce salmon production in the Columbia watershed above McNary Dam.

The LCRFDP had six parts: 1) Remove obstructions to salmon migration in tributaries to the lower Columbia River. 2) Clean up pollution in major tributaries like the Willamette River; 3) Screen water diversions to prevent the loss of juveniles in irrigation ditches, and construct fishways over impassable barriers in the tributaries of the lower Columbia River; 4) Transplant salmon stocks from above McNary Dam to the lower river; 5) Expand the hatchery program by remodeling existing hatcheries or building new facilities; and 6) Create salmon refuges by setting aside most of the tributaries below McNary Dam exclusively for the maintenance of salmon and steelhead runs (Laythe 1948). The hatchery program was one of six parts of the LCRFDP, but within a few years it was the dominant part. In the third year of the program (195 1) hatcheries and habitat consumed 49 and 5 percent respectively of the budget (USFWS 195 1).

The four programs discussed above illustrate attempts to develop cooperative management, research and enhancement programs for the Pacific salmon. They probably do not exhaust all such efforts, but they give some insight as to how managers were responding to the rapid decline of the salmon fisheries.

During this period (1920-1958), and especially during the 1930s and 194Os, the fishery in the Columbia River underwent significant change. Growth of the troll fishery made management of Columbia River salmon an international problem. After 1920 the chinook salmon runs into the river went into rapid decline from which they have not recovered. Depleted stocks, distant interception fisheries and rapid development of the Columbia’s water resources forced salmon managers to recognize that their activities had to be guided by scientifically sound information, and as a result, state agencies initiated research programs and universities in the northwest began training fishery biologists. One of the benefits of that research was improved survival of artificially propagated salmon in the 1950s and 1960s. Habitat degradation accelerated with major new construction of mainstem dams. The development of the basin’s hydropower potential presented the fishery managers with critical technical problems at a time when research was only beginning to generate the basic information needed to resolve those problems. At the same time, the huge economic potential of the hydro developments introduced a different and greater level of political pressure on managers.

B. MANAGEMENT ACTIVITIES

1. Hatcheries

Although it was becoming clear, as chinook harvest went into steep decline, that hatcheries were not maintaining production, it didn't diminish institutional enthusiasm for artificial propagation. In 1928, the State of Oregon increased its production of spring chinook by 53 percent and a few years later called for a doubling or tripling of hatchery production (OFC 1929, 1937). However, managers realized that if artificial propagation was ever going to meet its objective of maintaining the supply of salmon to the industry, the hatchery program had to grow and, more importantly, the operation of hatcheries had to be based on science (OFC 1933).

To develop a scientific approach to salmon conservation and production management institutions needed the services of trained biologists, however, management agencies, which were dominated by fish culturists, were reluctant to hire biologists; they didn't trust them and felt they didn't need them (Moore 1925). In 1936, a list of 271 positions in the Oregon Fish Commission included one fishery biologist (OFC 1937). In 1938, Oregon State College graduated its first class of trained Fish and Wildlife biologists and in the same year the Oregon Fish Commission established the division of research. By 1939, the Oregon Fish Commission listed five positions for fishery biologists (OFC 1939) and nine in 1941 (OFC 1941). In the early 1940s, the region was on the verge of a massive development of its water resources, development that would radically alter salmon habitat in the Columbia River. So at a time when scientific expertise was needed, management institutions were just taking the first steps toward acquiring appropriately trained personnel.

The immediate emphasis for the new scientific management was to develop accurate statistical data on the fishery and to improve hatchery practices. For the latter, research focused on sources of mortality in the hatchery primarily from diseases and the relative survival value of different practices such as the time and manner of releasing salmon to the river. Part of the reason hatcheries were given priority in research was the planned hydroelectric development of the Columbia Basin. Management institutions which were dominated by fish culturists naturally assumed that maintenance of salmon would depend on artificial propagation (e.g., OFC 1939). Instead of a balanced approach including a search for new alternatives, research supported the existing paradigm, which for 70 years, had based future production of salmon almost entirely on the promise of artificial propagation. There were alternatives which could have been considered. As early as 1892 Livingston Stone (1892) called for salmon parks - watersheds set aside for the production of salmon. The idea was revived in the 1930s by both Oregon and Washington (OSPB 1938; WDFG 1932) and salmon sanctuaries were originally part of the Lower Columbia River Fisheries Development Program (Laythe 1948). Although the concept has a long history, refuges as an alternative to, or in conjunction with hatcheries failed to materialize.

In spite of the continuing optimism, biologists recognized that the failure of artificial propagation to deliver on its optimistic promises could no longer be ignored. In a report published after his death, John Cobb, the Dean of the University of Washington College of Fisheries, listed artificial propagation as one of the threats to the salmon industry (Cobb 1930). Cobb was worried about the over optimism and lack of critical evaluation of the hatchery programs. Skepticism by biologists regarding the efficacy of artificial propagation was not limited to the Pacific

Northwest. At its 7 1st national meeting, the American Fisheries Society (AFS), heard John Gottschalk begin his report from the Division of Fish Culture with these words:

> ***"After reviewing statements of various officers of this Society [AFS] during the past few yearsfish-culturists must recognize that the most significant trend in fish culture is an increasing doubt as to the ability of fish hatcheries to perform the task assigned to them. " (Gottschalk, 1942)***

To maintain the hatchery programs in the face of continued depletion (Figure 8) managers had to renew optimism by initiating change. In 1920, most of the salmon released from hatcheries were fry - nearly 70 percent of the hatchery releases in 1920 (Cobb 1930). By 1958, there was a major shift to longer rearing periods and release at larger sizes, for example, in 1958, hatcheries in the state of Washington released 3.4 million fry, 38.3 million fingerling and 0.6 million yearling spring and fall chinook (Ellis and Noble 1959). Fish reared for longer periods (fingerlings and yearlings) needed to be fed nutritious diets and held in environments that prevented disease. Extensive research developed better feeds (e.g., Hublou et al. 1959), which when pasteurized seemed to reduce the incidence of certain diseases (OFC 1960).

In 1938, Congress passed an emergency measure to deal with declining salmon runs in the Columbia River. The Mitchell Act authorized the expenditure of $500,000 to correct the impacts of mainstem dams and other human activities in the basin. The first appropriation of funds was largely used to census salmon populations and inventory habitat in the Columbia River tributaries (Columbia River Intertribal Fish Commission (CRITFC) 198 1).

The Mitchell Act was amended in 1946 to permit the Secretary of Interior to enter into agreements with the states of Oregon, Washington and Idaho to use their facilities to enhance Pacific salmon. The $500,000 limitation was also removed. This amendment established the legal mechanism used to establish the Lower Columbia River Fishery Development Program described on page 33. The LCRFDP authorized the construction, relocation or renovation of 3 1 hatcheries in the Columbia Basin. However, only 21 of the hatcheries were built. In 1956, the word lower was dropped from the program and Idaho became an active participant (CRITFC 198 1).

Towards the end of this period, as the chinook salmon in the Columbia River continued to decline, a subtle but significant shift in the hatchery program took place. The original and longstanding objective of hatcheries was to maintain the supply of salmon - i.e., replace natural production lost because of habitat destruction and overharvest. While that was the goal, the evaluation of hatchery programs focused on a much narrower question: Do the salmon released from hatcheries contribute to the fisheries (e.g., Ellis and Noble 1959; Pulford 1970; Senn and Noble 1968)? This divergence between the goal and the evaluation led to this unfortunate outcome: The overall abundance of salmon could continue to decline but hatchery programs were considered a success as long as the cost of artificially propagating salmon was less than their economic contribution to the fishery. Under this approach to evaluation, as wild stocks continued to decline, in part due to hatchery operations, hatchery fish made up an increasing proportion of the total run which made them appear to be more and more successful. This reinforced confidence in artificial propagation while at the same time, hatcheries were failing to they could replace natural production, but they were evaluated only in terms of their economic contribution to the fishery. In the benefit-cost analysis of those evaluations, the cost of hatchery production did not include the loss of natural production resulting from hatchery operations.

2 . Harvest

Harvest managers also recognized the need to introduce science into the regulation of catch. In the early decades of the commercial fishery the condition of the resource was commonly judged by listening to the opinions of people working in the industry (OFC 193 1). That approach focused attention on the year to year variation in harvest. Managers were beginning to realize that catch data alone did not provide enough information to prevent over harvest and that a better measure was the catch per unit of fishing effort, especially if the data were interpreted after taking into account other biological, economic and hydrographic information (OFC 193 1). About the time harvest managers were beginning to recognize the importance of scientific information, a new fishery for salmon in offshore waters began creating a new set of management problems.

The troll fishery off the mouth of the Columbia River grew from a few boats around the turn of the century to 500 boats in 1915 and 1,000 boats in 1919 (Cobb 1930). World War I cut off the supply of flax and increased the cost of gill nets to the point that many gillnetters switched to trolling in 1919 (Martin 1994). In 1920, Smith (1920) estimated that there may have been as many as 2,000 trollers off the Columbia River.[6] Very early, salmon mangers recognized the problems that the troll fishery would create including the harvest of immature fish which decreased the amount and value of the catch (Smith 1920). Ocean tagging of chinook salmon off the west coast of Vancouver Island from 1925 to 1930 also showed that the troll fishery would create problems that were international in scope. Significant numbers of chinook salmon from the Columbia River were captured off Vancouver Island (Milne 1957) confirming that salmon undertook extensive migrations during their ocean residence and adding evidence to support the home stream theory.

During this period, the harvest of chinook salmon in the Columbia River averaged 15 million pounds, down from the average catch of 25 million pounds in the previous period. Harvest continuously declined from 1920 to 1958, so by the end of the period the average harvest of chinook salmon was 6.9 million pounds (average of the last five years 1954 to 1958). However, some of that decline can be attributed to the interceptions by the troll fleet which largely landed its catch outside the Columbia River ports and therefore would not be included in the catch records. Silliman (1948) corrected the total harvest of chinook salmon from the Columbia River to include an estimate of the troll caught fish. When the troll catch was added to the in-river harvest it reduced the apparent decline, however, even with the troll catch included the total harvest showed a marked decline after 1920 (Silliman 1948).

From 1920 to 1943, there were minor adjustments to the opening dates of the spring and summer fishery, but the total number of fishing days remained about the same ranging from 272 to 277 days from 1909 to 1942. In 1943, closures in May, June, January and December caused the first major reduction in fishing since 1909. There were 199 fishing days in 1943 and from that date

[6] There appears to be a discrepancy between estimates of the troll fishery made by Cobb (1930) and Smith (1920).

the fishery has become progressively more restricted. At the close of this period in 1958, only 115 days of fishing were permitted, a loss of 157 days (Wendler 1966). The growing troll fleet which could fish beyond the 3-mile limit of state jurisdiction was largely uncontrolled until 1949 with the enactment of a tri-state compact (Oregon, Washington and California) which brought into existence the Pacific States Marine Fisheries Commission (PSMFC).

As the size of the runs into the river declined, competition among fishermen using different kinds of gear intensified and erupted from time to time in “fish wars.” Eventually the gillnetters proved to be the most politically powerful group and by 1950, the only legal commercial fishing gear allowed on the river were the drift gill net and Indian dip nets (Wendler 1966). The other gear, such as fish wheels, traps, whip and haul seines, purse seines and set nets **were** eliminated often by initiative petition.

3. Habitat

The 193 l-32 Biennial Report of the Oregon Fish Commission **contained** this statement:

> ***“What might be termed an industrial, vari-colored map of the Columbia River Basin, based on data carefully collected over a period of fifteen years, has been prepared by the Fish Commission during the current year. Close scrutiny reveals the fact that approximately 50% of the most important productive area within the basin has been lost to the (salmon) industry by the construction of dams for irrigation and power, thus isolating spawning areas."***

Significant habitat degradation took place in the late 19th and early 20th centuries (Lichatowich and Mobrand 1995; Wissmar et al. 1994), however, it was not until the late 1930s that managers attempted to determine the quantity and quality of habitat in the basin. In addition to the Oregon Fish Commission study referred to above, the Bureau of Fisheries carried out extensive and intensive surveys of salmon habitat in the basin, from 1934 to 1942. Many of these surveys were carried out as part of the Mitchell Act. The purpose of the survey was to determine the condition of habitat in the various tributaries with respect to migration, spawning and rearing of anadromous fishes. Ultimately, the habitat survey was to be used as a basis for improving habitat and increasing fish production (Rich 1948). However, it’s not clear how this information was used, except as a baseline for similar surveys conducted 50 years later (McIntosh et al. 1994). In fact,shortly after the habitat survey was completed, the rapid development of the basin’s hydropower and the construction of the mainstem dams caused salmon biologists to shift attention from the tributaries to the problems of adult and juvenile passage through the mainstem.

Grazing and timber harvest, largely carried out without regard for their effects on salmon habitat, continued to degrade the quality of spawning and rearing areas in many of the basin’s tributaries. It appears that the additional information obtained through the habitat surveys conducted in the 1930s and 1940s resulted in little additional habitat protection.

After 1930, salmon managers experimented with electric barriers to keep juvenile salmon out of irrigation diversions, and later, the diversions were slowly protected with rotary screens to prevent entry by juvenile salmon. Where adequate screens were put into use, juvenile salmon were prevented from entering the diversions. However, the direct mortality of juvenile salmon diverted into irrigation ditches was not the only problem created by the withdrawal of water from rivers. Low flows below the diversions eliminated rearing habitat and blocked migration. Low flows in natural stream channels often caused water temperatures to rise to lethal levels for salmonids. In some cases the streams were left with no water in the natural channel. In the 1930s there appeared to be little room for accommodating salmon and agriculture especially in streams east of the Cascade Mountains. Agriculture was obviously considered the "highest and best" use of water. Salmon were a lower priority as expressed by B. E. Stoutmeyer, district council for the Bureau of Reclamation:

> ***"... Water appropriators, both on the government project and on the private projects which had already appropriated all of the low water flow, have vested rights which could not be taken away from them unless they were paid for such rights. As there are about 100,000 people living in the Yakima Valley, all dependent on irrigation, I do not believe any serious argument could be made that the water should be taken from the farms and orchards to improve fishing conditions." (Stoutmeyer 1931)***

The screening of irrigation ditches started in the 1930s, 70 years after the mass destruction of juvenile salmon had begun, but the screening program was not rapidly implemented. Irrigation ditches were still being screened in the 1950s, 1960s and 1970s and some are still not effectively screened (NPPC 1986).

Though major habitat degradation had taken place in the tributaries by the 1930s and would continue to decline in some basins, the mainstem of the Columbia and Snake rivers still contained productive spawning and rearing habitats particularly for fall chinook salmon (Fulton 1968). However in the 1930s, hydroelectric development and the construction of mainstem dams began eliminating those productive mainstem habitats. Mainstem dams not only eliminated spawning and rearing habitats, but the additional mortality of juvenile and adult salmon in the reservoirs and at the dams reduced the overall productivity of the river reaches and tributaries not affected by the dams. Habitat loss which started in the tributaries had been extended to the mainstem so the entire freshwater range of salmon was affected. Production declined sharply after 1940 and there has been no indication of a sustained recovery in the past 50 years.

In 193 1, the Oregon Fish Commission adopted a policy to protest every application for a dam or irrigation project filed with the state engineer until the project included plans for safe upstream and downstream passage (OFC 193 1). However, national economic conditions accelerated the pace of development in the Columbia River. The great depression and the huge dust storms in the southwest set millions of jobless city dwellers and farmers on a mass migration, and to many national leaders the Pacific Northwest was the promised land where they would find a new, productive life (Neuberger 1938). To support resettlement, the northwest needed to develop its natural resources, including the hydroelectric potential of its greatest river, the Columbia. As the region began a massive development of its water resources, including hydropower and irrigation projects it was clear to biologists that the basin's salmon would be devastated. By 1939, biologists recognized that they needed to be included in the initial planning of water resource development programs to have any chance of saving the salmon in the Columbia River (Rich 1940).

The development of the basin's hydropower increased especially in the later part of this period. Up to 1920,27 dams had been built in the basin (Table l), but in the 38 years from 1920 to 1958, 37 dams were built, many of them much larger than the earlier structures (Table 3). Nine of the new dams were on the mainstems of the Snake and Columbia rivers. Part of the original plan for the development of the basin's hydropower resources included a program to salvage the Pacific salmon especially those stocks whose home streams were above the site of the proposed McNary Dam. The plan included important habitat provisions. Obstructions to migration in the tributaries were to be removed; pollution, especially in the Willamette River was to be reduced; irrigation diversions were to be screened; and the states of Oregon and Washington were to set aside the tributaries below McNary Dam as salmon refuges. The program did screen many of the irrigation diversions east of the Cascade Mountains. However, the fish refuges failed to materialize.

C. MANAGEMENT FRAMEWORK

From 1920 to 1958, biologists made significant advances in their understanding of the life history and biology of chinook salmon in the Columbia River. Although the homing of salmon back to their natal stream, the so called home stream theory, had been the subject of a long debate among biologists (e.g., Huntsman 1937; Rich 1937a, 1937b and references cited earlier), by 1940 it was generally recognized that the species of Pacific salmon were comprised of local populations' and members of those populations returned to their natal stream to spawn after extensive ocean migrations (Rich 1939). By 1939, the home stream theory was so well accepted that hatchery managers recognized and began to discuss its implications. At least some salmon culturists recognized that homing and the existence of local populations made the usual practice of transferring fish among streams undesirable (OFC 1939). Biologists also suggested that local populations of salmon were adapted to the environment of the home stream (Craig 1935) and that management had to protect each of those populations if it was going to be successful.

> ***"...Knowing further that each race[7] is self-propagating, it becomes perfectly apparent that all parts of the salmon run in the Columbia River must be given adequate protection if the run as a whole is to be maintained. The protection of only one or two portions of the run will not be sufficient, inasmuch as certain races will be left entirely unprotected." (OFC 1931)***

The acquisition of more and better information on the biology of the Pacific salmon and their habitats throughout the basin began to generate new ideas and a new management framework for Pacific salmon began emerging (e.g., Rich 1939). Research was yielding new information which challenged the existing management framework. The attempt to control and simplify the production process through artificial propagation was giving way to a framework which recognized an underlying complexity in the structure of the salmon's population and life histories and the need to understand and conserve the relationship between the salmon and their habitat. For 60 to 70 years managers pursued artificial propagation with a blind faith, but by the 1930s the hatchery programs were being openly questioned. John Cobb (1930) called the "almost

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[7] The term race used here is equivalent in current usage to the term stock as defined by Ricker (1972).

Table 3. **List of dams constructed from 1920 to 1958 in the Columbia Basin. (Source: Lavier 1976).**

Dam	River	Height (ft)	Date
Beulah	Malheur		1935
Big Cliff	North Santiam		1954
Black Canvon	Pavette		1924
Bliss	Snake	120	1950
Bonneville	Columbia	197	1938
Brownlee	Snake	395	1958
Bullv Creek	Malheur	100	1963
Chief Joseph	Columbia	205	1955
C. J. Strike	Snake	132	1952
Cle Elum	Cle Elum	135	1933
Cottage Grove	Willamette	95	1942
Dee Dam	Hood		1925
Detroit	North Santiam		1953
Dexter	Willamette	57	1955
Dorena	Willamette	115	1949
Easton	Yakima	60	1929
Grand Coulee	Columbia		1941
Leaburg	McKenzie		1929
Lewiston	Cleat-water		1927
Lookout Point	Willamette		1954
McKay	Umatilla	lOO+	1926
McNary	Columbia	183	1953
Merwin	North Lewis	313	1931
North Fork	Clackamas		1958
Ochoco	Crooked	110	1930
Owvhee	Owvkee	330	1932
Pelton	Deschutes	204	1957
Powerdale	Hood	30	1923
Rim Rock	Yakima	220	1925
Rock Island	Columbia	100	1933
Roza	Yakima	67	1940
The Dalles	Columbia	260	1957
Thief Valley	Powder	70	1932
Unitv	Burnt	76	1937
Vaseaux	Okanogan	6	1921
Wallowa	Wallowa		1929
Wapato	Yakima		1942

idolatrous faith" in hatcheries a threat to the fishing industry and hatcheries were considered an impediment to the development of effective conservation programs (Rich 1941). In the absence of critical evaluation, artificial propagation evolved into a myth - a set of unsubstantiated but strongly held beliefs - which for 70 years suspended healthy skepticism, impeded improvements and contributed to the depletion of natural production.

In the mid-194Os, biologists had to face the prospects of a Columbia River totally controlled by a series of mainstem dams and degradation of the remaining salmon **habitat** in the mainstem. Biologists generally understood the kind of consequences that the planned hydro development of the Columbia River would have on the Pacific salmon (e.g., Craig 1935; Griffin 1935; O'Malley 1935; Rich 1935,194O). By the mid- 1940s salmon managers were handed a crisis: Salmon above the McNary Dam were given little chance of survival (USFWS and WDF 1946) and salmon were given a lower priority than hydroelectric development, i.e., salmon concerns would not prevent or delay development. Assistant Secretary of the Interior, W. W. Gardner, summarized the situation in a memo entitled, 'Columbia River Dams or Salmon'*:

> ***"...it is therefore the conclusion of all concerned that the overall benefits to the Pacific Northwest from a through-going development of the*** *Snake* ***and Columbia are such that the present salmon run must be sacrificed. This means that the departments efforts should be directed towards ameliorating the impact of this development upon the injured interests and not toward the*** *vain* ***attempt to hold still the hands of the clock. " (Gardner 1947 p. 4)***

Gardner's memo was approved by the Secretary of Interior on March 13,1947.

Faced with the inevitability of mainstem dams and the pessimistic predictions of their effects, the state and federal agencies charged with protection and management of the salmon abandoned the emerging management framework and chose to maintain the status quo - nearly complete dependence on hatcheries to make up for lost natural production. The LCRFDP which emphasized the use of hatcheries and the transfer of production from the upper to the lower river ignored a key concept in the emerging framework: the stock structure of Pacific salmon and its implications to management. A management framework based on the conservation of locally adapted stocks would not emerge again in the Columbia River until the 1970s and it would not begin to influence management until the 1980s and 1990s after some stocks declined to the point they were protected under the federal Endangered Species Act.

To deal with the challenge posed by the hydroelectric development of the Columbia Basin, managers chose the familiar, the status quo. The management framework remained tied to artificial propagation and the simplification of the production process. Unfortunately, managers not only opted for the status quo, but failed to give strong support to the continuation of research on the salmon's biology.

> ***"When the Lower River Program was introduced as an aid in checking the decrease in salmon population it was promoted as an action program that could be inaugurated immediately without delay for lengthy research. The states emphasized definitely that additional research was not needed before this program could be undertaken. The keynote was 'action.' Later when money***

became available and delays were encountered in obligating this money it was acknowledged that there were many shortcomings in the program which could not be overcome without additional research." (PNWFC 1950)

Why was research given a low priority in the LCRFDP? Perhaps the salmon managers believed that research conducted prior to the mid-1940s had given them all the information they needed to maintain salmon in a highly developed Columbia River. Or alternatively, managers may have de-emphasized research because earlier investigations found reasons to question the prevailing attitudes towards artificial propagation and the operation of hatcheries (Cobb 1930; Rich 1920).

The development of the water resources of the Columbia Basin from the mid-1930s to the mid-1970s transformed the river into an efficient producer of electricity. It also produced a regulated river system capable of irrigating crops, controlling floods and transporting goods. The model for this development was the machine. The historian Richard White (1995) has called the developed Columbia River an organic machine. While the machine model was successful in producing a highly controlled river which was put to work for man, the same model failed to conserve or restore Pacific salmon in the Columbia River.

Although the mechanistic world view and its primary metaphor. the machine (Pepper 1972), has a long history in science, it gained major support in ecology following World War II, due in part to the successful use of systems engineering during and immediately after the war. Large scale hydro development in the mainstems of the Columbia and Snake rivers took place during a period of post war euphoria buoyed by the belief that the region could engineer a better river. Belief in the power of engineering naturally shifted to natural resource management including the management of Pacific salmon. During the 195Os, ecology used the language of engineering and economics and the model of the machine to describe and analyze ecosystems (Golly 1993). The application of that approach to the management of Columbia River salmon led to the belief that problem of making salmon and dams compatible could be successfully engineered.

The machine is a particularly appealing model for a management framework that depends heavily on artificial propagation. Just as hatcheries easily adapted to the Progressives view of highest use, in the 1950s they also slipped easily into the machine model of salmon production systems. Hatcheries were already designed to resemble factories (Lichatowich 1988) and the machine model is consistent with one of the earliest aims of artificial propagation: The desire to control and simplify the production process. Machines are under the control of their human designers.

The highly mechanistic approach to management has difficulty in incorporating several features of the natural ecosystem such as habitat complexity and connectivity and the interaction between complex habitats and life histories of the salmon. Climate fluctuation on short- and long-term scales that exert strong influence on salmon production are not compatible with assumptions of ecological equilibria, a key assumption when using the machine model. Stock diversity implies that some of the parts of the machine are not interchangeable. These inconsistencies did not begin to raise questions about the efficacy of the management framework until well into the next period.

What would the production of salmon in the Columbia River look like today if the framework emerging in the late 1930s and early 1940s had not been abandoned but was used as the basis for salmon restoration in the basin? This question is impossible to answer but it is possible to derive some insight by reviewing the restoration program on the Fraser River. There are too many differences in the two basins to make a direct comparison, but this discussion of management frameworks will be enhanced by a general comparison of the restoration programs on the Columbia and Fraser rivers.

The current program to restore Columbia River salmon can trace its roots back to 1948 and the LCRFDP. A decade earlier a major restoration program for the Fraser River was initiated. On August 4, 1937 the United States and Canada ratified a convention for the protection, preservation and extension of the sockeye salmon fishery of the Fraser River system. The convention which created the International Pacific Salmon Commission (IPSFC) was the culmination of 45 years of negotiation and meetings between the United States and Canada (Roos 1991).

The IPSFC's initial program had four key elements: 1) Correct the problem at Hell's Gate. The blockage at Hell's Gate was an obvious bottleneck that had to be corrected. 2) Protect the watershed. One of the early policy statements of the IPSFC put the Canadian Government on notice of its intent to protect salmon habitat in the watershed. 3) Protect the stocks. The IPSFC recognized that sockeye salmon in the Fraser River were separated into different socks, each with specific spawning and rearing areas, run timing and environmental requirements. Management had to be based on stock conservation. 4) Hatcheries were given a low priority (Roos 199 1). The elements of this program were consistent with the knowledge of the salmon and the emerging framework in the Columbia Basin in the mid- 194Os, however, the IPSFC's restoration program was quite different than the approach taken in the Columbia River.

In 1960, after the U.S. hatcheries began showing improved survival, the IPSFC reviewed artificial propagation as a mitigation tool. The review was responding to proposals to build major hydroelectric and flood control dams in the Fraser River, many of them downstream from juvenile rearing areas in the basin. The IPSFC concluded that hatcheries were not a proven method of maintaining the localized stocks of Fraser River sockeye and pink salmon (Andrew and Green 1960).

With the exception of minor amounts of production from three spawning channels, successful restoration of the Fraser River sockeye salmon was not the result of technological enhancement programs (Hilbom and Winton 1993). Production was increased by strengthening the processes leading to natural production and not by emphasizing artificial propagation. From 1950 to 1978 the total annual run averaged 5.55 million fish compared to 3.31 million fish from 1918 to 1946 (after Hell's Gate but before IPSFC actions took effect). Recent run sizes have been 12 million fish in 1991, 13 million in 1985, 15 million in 1986, and 22 million in 1990 (Roos 1991; Pacific Salmon Commission (PSC) 1991; PSC 1994). The IPSFC ceased to exist in December 1985. It was replaced by the PSC (Roos 1991).

Biologists working in the Columbia Basin had the same information as the biologists working in the Fraser River, but the salmon management institutions in the two rivers took very different approaches to restoration. Part of the difference can be explained by the different social context in the two basins - the strong emphasis on hydroelectric development in the Columbia River even at the expense of the salmon was a major difference. Salmon management conformed to that social context. It would be difficult to estimate the cost to the Columbia River salmon due to the approach taken in the 194Os, and possibly a different framework might not have made a difference. However, the Fraser River's approach will always remain the road not taken on the Columbia River and a lingering uncertainty.

D. SUMMARY

Status Chinook harvest declined throughout this period to an overall annual average of 15 million pounds. The fishery underwent a major shift from in-river to troll fisheries. The construction of mainstem dams added a major new factor in the degradation of salmon habitat.

Response As the salmon declined and traditional approaches to management appeared unable to arrest the depletion, the need to place management on a scientific footing was recognized. The first comprehensive surveys of salmon habitat in the basin were completed. The depleted status of the salmon resulted in several attempts to share scientific information among salmon managers and to develop restoration plans. Managers ignored scientific information on the stock structure of the salmon and the past failures of hatcheries to reverse the salmon's decline and turned to artificial propagation as the primary means of mitigating the effects of mainstem dams.

Management Framework The massive development of the basin's water resources for power production, irrigation, flood control and transportation was enhanced by the post World War II science of systems engineering. The same approach was also popular in ecology. Engineers and many ecologists assumed the machine was a reasonable model of the systems they sought to analyze, improve or manage. Artificial propagation easily made the transition to the new framework because, like the previous frameworks, control and simplification of salmon production were important elements. The artificial production system achieved a higher level of simplification by circumventing most of the salmon's fresh water life history through the release of smolts.

V. 1959 TO 1990

A. STATUS OVERVIEW

The construction of mainstem dams was well underway by 1960, however several major structures remained to be built including Hells Canyon, Lower Granite, John Day, Cougar, Little Goose, Lower Monumental, Ox Bow, Priest Rapids and Wells dams. In addition, the construction of flood control and storage reservoirs in the United States and Canada drastically altered the hydrograph by the mid-1970s. In 1960, the salmon runs into the Columbia River were depressed relative to the peak years of the fishery (Figure 9) and by the end of the period, fall and spring/summer chinook and sockeye salmon from the Snake River were under the protection of the federal Endangered Species Act (ESA). Other stocks are being considered for ESA protection. The wild coho salmon from the lower Columbia River were declared extinct (Weitkamp et al. 1995). Seventy six stocks are considered at high or moderate risk of extinction or of special concern (Nehlsen et al.1991). Of the 157 extant stocks of salmon in the Columbia Basin Fish, 9 native stocks were considered healthy in one survey (CBFWA 1991) and 10 in another (Huntington et al. 1994).

As the salmon declined to lower and lower levels of abundance, reports describing their status and plans for their restoration began to appear with increasing frequency. The basic problems identified in those plans differed little from those described in the previous period. Funding for restoration increased dramatically. Prior to 198 1, $494 million were expended on salmon protection and restoration; in the next 11 years (198 1- 199 1) restoration consumed $1.3 billion, including the cost of lost revenue due to flow manipulations for salmon (GAO 1992). The NPPC (1994) estimates that its restoration program could cost as much as $450 million in 1995 in direct and indirect costs. So far there is no indication of a reversal of the depleted condition of the salmon and steelhead especially in the middle and upper river. Similar to the previous period, there were several conferences and symposiums convened to search for ways to increase the production of salmon. Two of those conferences, one regional and one local are discussed below.

1. Pacific Salmon Rehabilitation Conference

In 196 1, Governor William Egan of Alaska convened a conference to discuss the decline of Pacific salmon throughout the northwest, review present research and management techniques and search for ways to develop a coordinated, coast-wide program (Alaska Department of Fish and Game (ADFG) 196 1). Generally the problems identified by the conference attendees were similar to the problems identified in the earlier conferences, and as might be expected, the growing problems associated with dams received more emphasis. The need to investigate the genetics of salmon populations and the importance of individual populations in management were other areas of concern identified in the Governor's Conference.[8]

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[8] The importance of individual populations was known since the 193Os, however, the conference gave it new emphasis.

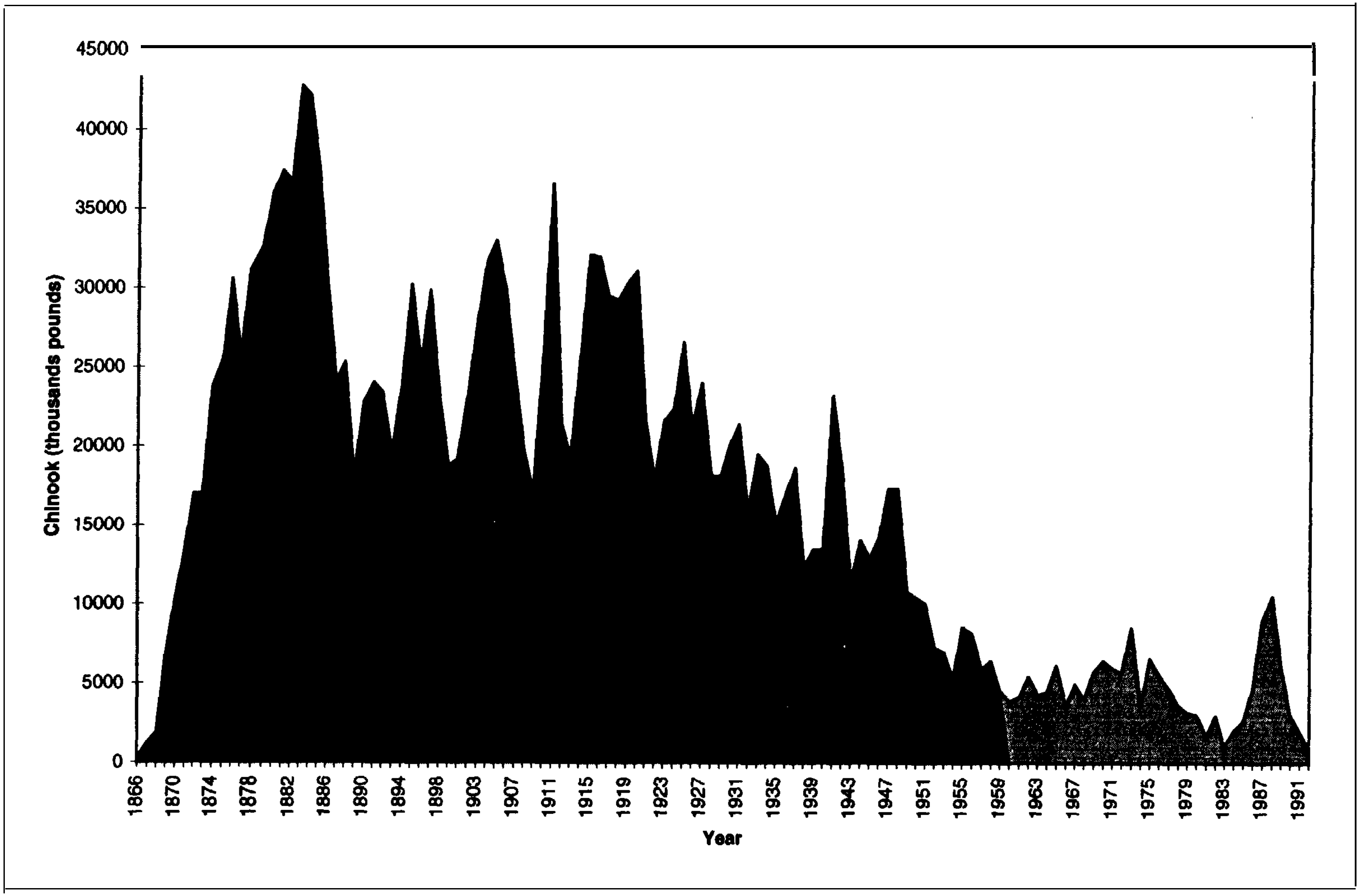

Figure 9. The harvest of chinook salmon In the Columbia Basin. The highlighted region (1959-1992) is discussed in the text, (Source: Beiningen 1976; *ODF W AND WDF 1993)*

The conference differed from the earlier ones over how to handle coordination among the states. The need for closer coordination was recognized as a high priority by the 196 1 conference, but the participants rejected the idea of a super agency or management council. Recall that an independent commission with authority to manage the salmon fishery and conduct research was recommended earlier by both Oregon and Washington. In addition, the report on the 1961 conference described another problem:

> ***"It was disquieting that there was little argument or discussion among the scientists present, as there might have been had they been free of controls. Each spoke as a representative in one way, or the other, of his organization, as though departmental 'policies' were involved in anything they might say. No antagonism or differences of opinion appeared even if present. This is not a healthy or normal state as far as scientists are concerned, because it is in diversity and originality of ideas that there exists opportunity for improvement or change, so badly needed in fisheries biology. It was most apparent that organizational controls dominated. The conference brought out clearly that conservatism, the deadly sameness of the methods and results inherent in this close organizational control. (ADFG 1961 - Report of the Evaluating Committee p. 14)***

The conference clearly identified the politicization of salmon management which was probably a consequence of pressures brought on by shrinking fisheries, the rapidly deteriorating habitat, ineffective hatcheries and the pressure for more development and habitat degradation.' The increasing politicization and polarization of fishing groups and management institutions on the Columbia River led to a symposium on the status and future of salmon and steelhead in the basin in 1976 (Schwiebert 1977).

2. Columbia River Salmon and Steelhead Symposium

The Columbia River Salmon and Steelhead Symposium clearly showed the impact of the expansion of fisheries research following World War II. Biologists discussed passage problems and possible solutions at mainstem dams (Ebel 1977), stream classification (Horton 1977), computer modeling (Reimers 1977), the genetic effects of interbreeding between hatchery and wild fish (McIntyre and Reisenbichler 1977), the effect of land use or riparian vegetation and salmon habitat (Saltzman 1977), and wild fish management (Bjomn 1977). After 100 years of failing to maintain the supply of salmon and reverse the decline of chinook salmon, Schwiebert (1977) found it surprising that many biologists still believed hatcheries could replace lost production due to habitat destruction and that the mitigation myth was still strongly adhered to. Mitigation focused on technology: hatcheries, mechanical devices at the dams to bypass juveniles and transportation. After 100 years of failing to demonstrate an ability to make up for watershed degradation, some biologists still had faith that hatcheries and technology would be successful:

> ***"Hatcheries have played a major role in maintaining and enhancing runs of anadromous salmonids in the lower Columbia River, and can provide the means***

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[9] This problem may also explain, in part, the approach taken to salmon restoration in the mid-1940s which was discussed in the previous section.

of rebuilding future runs in the upper Columbia and Snake River systems to the levels that existed before the dams. " (Ayerst 1977 p. 84)

"We believe that if things proceed as they are now, combining the traveling screens and placing them in operation on schedule, expanding the transportation effort on schedule, and adding the spillway deflectors at the dams to reduce the nitrogen concentrations, we can restore the adult steelhead trout runs to their former levels within two to three years. After the Snake River Mitigation Plan is approved by Congress, *it seems possible that we can establish adult runs of both steelhead trout and salmon in far greater numbers than existed before. " (Ebel 1977 p. 39)*

Anthony Netboy (1977) disputed the idea that given enough money and technology the Columbia River salmon could be restored. He cited his world-wide studies of salmon that showed once a major salmon fishery goes into decline it is difficult to bring it back no matter how much money is spent.

Overall the symposium presented several approaches to the problem of arresting the decline of salmon, but it failed to answer critical questions. For example, Lane (1977 p. 158) pointed out that the region needed to know to what extent increased flows would cause increased juvenile survival and further: ". ..who is going to make the final decisions as to what use or uses have what priorities for the Columbia River water?" The flow survival question is still not resolved in 1996.

The region was rapidly gaining in knowledge about the chinook salmon, however, the greater knowledge was making little difference in arresting the decline and improving production (White 1995). The new knowledge and expanded staffs did produce an impressive series of status reviews and restoration plans including:

- Oregon Fish Commission (1962),
- Columbia Basin Inter-Agency Committee (1965),
- Pacific Northwest River Basins Commission (1972),
- Pacific Northwest Regional Commission (1976),
- Columbia River Fisheries Council (1978),
- Columbia River Fisheries Council (1980),
- Columbia River Fisheries Council (198 l),
- Salmon and Steelhead Advisory Commission (1984), and
- the Columbia River Management Plan (Amett et al. 1988)

In 1980 the Northwest Power Act created the Northwest Power Planning Council which has prepared a series of plans for restoration of the Columbia River salmon. The Council's Fish and Wildlife Program is currently being reviewed by an independent scientific group and will not be discussed here. However, to date the Council's program has not reversed the decline in chinook salmon.

B. MANAGEMENT ACTIVITIES

1. Hatcheries

As this period (1959-1993) got underway, research initiated in the 1930s and intensified after World War II, began to yield positive results. Improved diets, better disease treatments, and improved hatchery practices produced healthier smolts which began contributing to the fisheries in large numbers (Lichatowich and Nicholas in press). After 1960, hatchery programs for chinook salmon increased rapidly. From a release of 61 million chinook salmon in 1960 the program grew to about 144 million in 1989 with a peak of 160 million in 1988 (Figure 10).

Nearly 90 years after it was initiated, the hatchery program in the Columbia River was subjected to comprehensive scientific evaluation. Fall chinook salmon from 13 hatcheries for the brood years 196 1 to 1964 were marked by removing a fin or a combination of fins and the returns to the fisheries and the hatcheries were evaluated through a rigorous and comprehensive sampling program. The fishery from southeast Alaska to northern California was monitored for marked fish and the resulting analysis showed that 14 percent of the chinook salmon caught were hatchery reared fall chinook from the Columbia River (Wahle and Vreeland 1978). The results of the study were encouraging, and they confirmed that hatchery programs for fall chinook contributed to the fishery and the economic value of that contribution exceeded the cost of production.” The evaluation of fall chinook from the Columbia River hatcheries was repeated with the 1978 to 1982 broods, and while the contribution was still positive, survival was about half that exhibited in the earlier study (Vreeland 1989). The change in survival probably reflected a change in ocean conditions that occurred in 1976. While these two studies were the first comprehensive, scientific evaluations of the hatchery program for chinook salmon, the scope of the questions asked were too narrow.

The evaluations asked this question: Do hatcheries make a contribution to the fisheries and is the economic value of that contribution greater than the cost of operating the hatcheries? They failed to ask the other important question: Can hatcheries replace production lost as a result of habitat destruction, loss of biodiversity and over fishing? The use of artificial propagation as a mitigation tool was based on the assumption that the answer to the second question was yes. It has become clear that this assumption is false.

Hatchery reared chinook salmon began to make measurable contributions to the fishery, in part, because of research which showed better returns could be obtained if the juveniles were released at a time in their life cycle when they were undergoing the transformation from parr to smolt (Wallis 1968). Smoltification is a physiological change in juvenile salmon associated with their migration to sea. Longer rearing in hatcheries begun in the last period (192 1-1958) was extended so that most of the juvenile salmon released during this period were smolts. In 1920,64 percent of the artificially propagated chinook salmon in the Columbia River were released as fry (Cobb 1930). Not all of the remaining 36 percent were released as smolts; some were released as

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[10] Cost of hatchery production was limited to the dollars spent on hatchery operations. Cost accounting did not include ecological costs, i.e., the loss of natural production through mixed stock fisheries or the loss of fitness due to interbreeding between hatchery and wild fish.

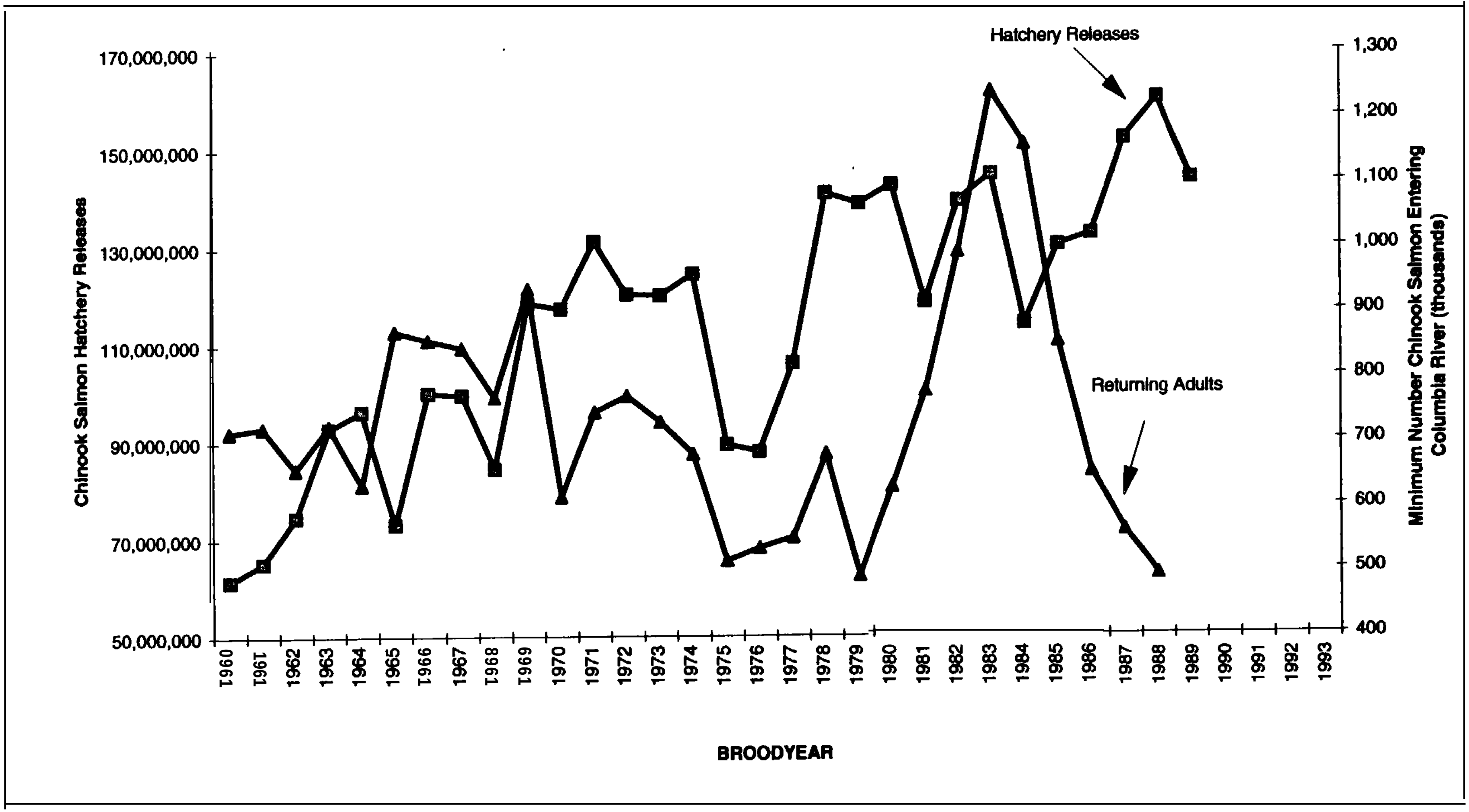


Figure 10. Number of juvenile chinook salmon (all races) released in the Columbia River by broodyear and the minimum number of adult chinook salmon entering the river. Adult returns are offset by four years so they roughly correspond to the juvenile releases. *Sources: Smith and Wahle 1981; ODFW and WDF 1993; and unpublished data from the CIS*)

presmolts or fingerlings. In 1960, only 6.3 percent of the juvenile chinook salmon released from hatcheries were classed as non-migrants or presmolts (Smith and Wahle 198 1).

The growth of the smolt release program for anadromous salmonids paralleled the growth of put and take stocking programs for resident trout. Both measured success in terms of the contribution to the harvest. A catchable trout "survived" if it lived long enough to be caught. Survival measured as the ability to complete the life cycle was not part of the program (Wood 1953). The river became a stage prop used in the transfer of trout from the hatchery to the angler. Actual condition of the habitat, carrying capacity and food gradients need not be considered (Wood 1953). Likewise, the smolt release programs for anadromous salmon limited the river's function to simply a channel which carried juvenile salmon to the sea (Ortman et al. 1976). Success in the smolt program was at best measured in terms of recovery in the fishery and frequently only in terms of numbers or pounds of smolt released.

Doubling the hatchery program for chinook salmon did not result in a sustained reversal of the decline from earlier years (Figures 11, 12, and 13). Artificially propagated salmon now make up about 80 percent of the returning salmon and steelhead (NPPC 1994) and to some that statistic is a measure of success, however, it would be difficult to argue that hatcheries have been successful in meeting their mitigation objectives while the river is experiencing the lowest runs in recorded history. Focusing hatchery evaluations on narrowly constructed cost-benefit analysis allowed managers to declare them a success while at the same time the program was failing to achieve its mitigation objectives and total production in the basin continued to decline.

In 1957, the Lower Columbia River Fisheries Development Program dropped the Lower designation and began attempting to restore salmon above McNary Dam. Idaho entered the program in 1959 (Delarm et al. 1989). From a beginning in 1949 with a budget of $1 million, the LCRFDP grew to about $9 million in 1986. The program's early emphasis on hatcheries has continued; in 1986,79 percent of the budget was expended on hatchery operation and maintenance whereas 10.5 percent was expended on screening irrigation ditches and stream improvement (Delarm et al. 1987). In addition to the LCRFDP, major mitigation programs were implemented in the mid-Columbia and the lower Snake rivers.

As the salmon released from hatcheries achieved higher levels of survival, benefits accrued to the fisheries but the increasing number of salmon of hatchery origin created new problems. Fisheries targeting the expanding hatchery production harvested a mixture of hatchery and wild stocks. Since survival of salmon from fertilized egg to smolt was greater in the protected hatchery environment compared to the natural river, hatchery stocks could sustain a higher harvest rate than wild populations and still meet their production targets. When the hatchery stocks are fully exploited, wild populations are often over harvested (Flagg et al. 1995). This situation is aggravated when habitat degradation decreases the productivity of wild stocks causing depletion to accelerate. The extinction of the lower river coho was in part due to the mixed stock fisheries.

Concerns were also raised regarding interbreeding between hatchery and wild salmon (Calaprice 1969). Two studies conducted in the 1970s addressed that concern and both showed that adults of hatchery origin produced progeny that survived at a lower rate than progeny of wild parents (Chilcote et al. 1986; Reisenbichler and McIntyre 1977). These two studies showed that at least in some cases hatchery operations imposed a cost on wild production that was not being

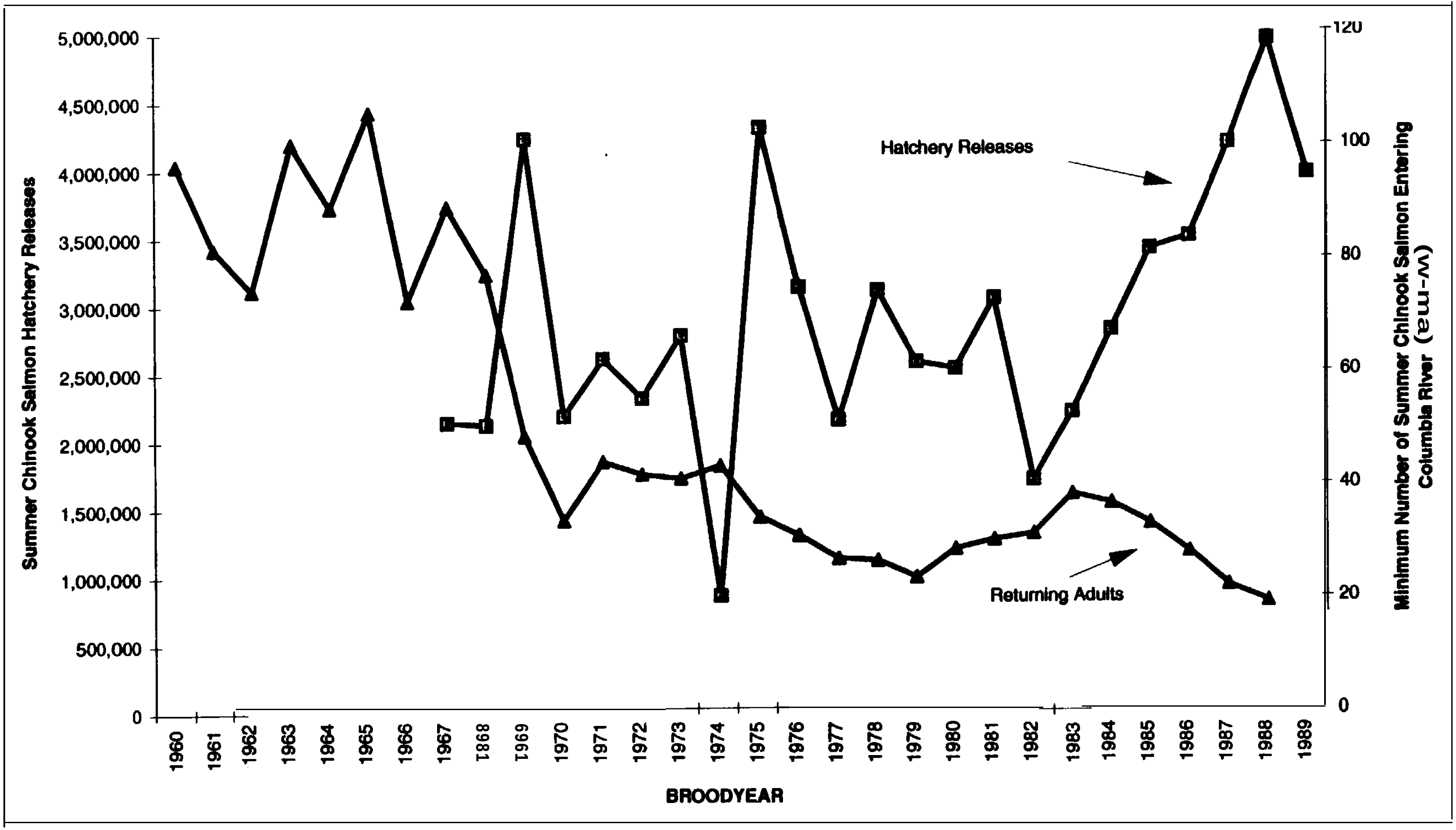
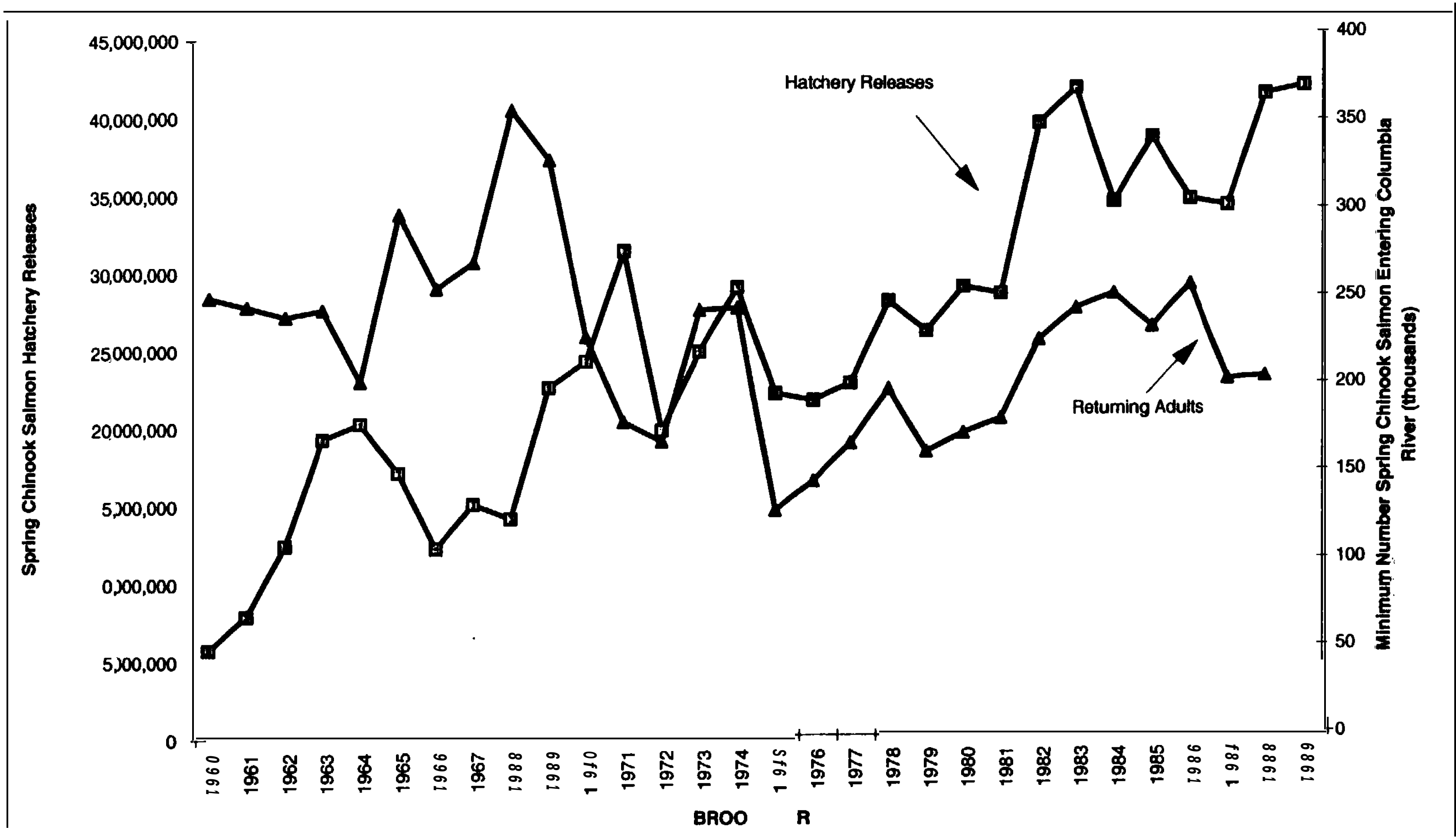
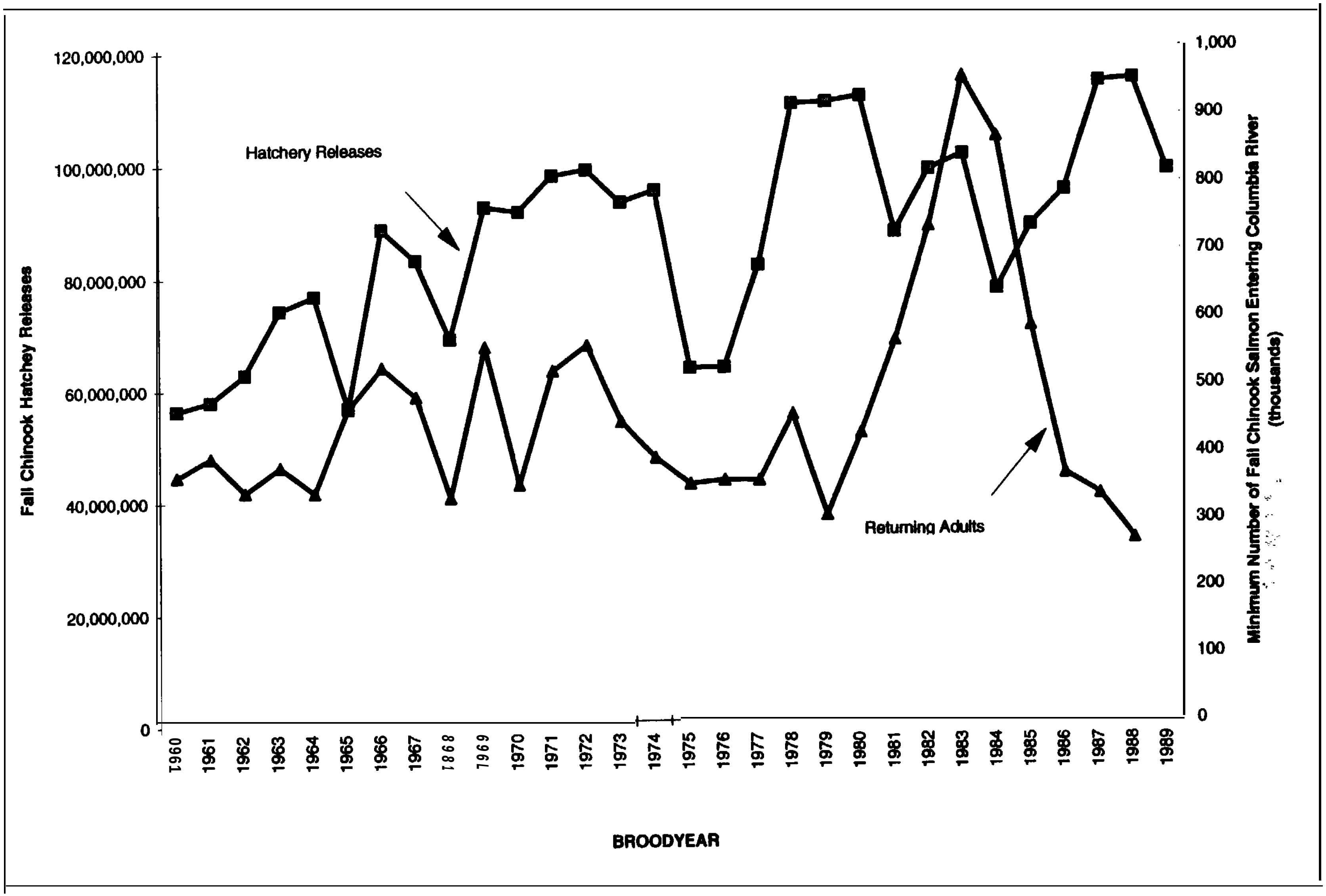


Figure 11. Number of juvenile summer chinook salmon released from Columbia River hatcheries and minimum number of adult summer chinook salmon entering the river. Adult returns are offset by four years so they roughly correspond to the juvenile releases. (*Sources: Smith and Wahle 1981; ODFW and WDF 1993; and unpublished data from the CIS*)



12. Number of juvenile spring chinook salmon released from Columbia River hatcheries and minimum number of adult spring chinook salmon entering the river. Adult returns are offset by four years so they roughly correspond to the juvenile releases. (*Sources: Smith and Wahle 1981; ODFW and WDF 1993; and unpublished data from the CIS*)



g 13. Number of juvenile fall chinook salmon released from Columbia River hatcheries and minimum number of adult fall chinook salmon entering the river. Adult returns are offset by four years so they roughly correspond to the juvenile releases. (*Sources: Smith and Wahle 1981; ODFW and WDF 1993; and unpublished data from the CIS*) accounted for in cost-benefit evaluations of artificial propagation. The biological and ecological costs of conventional hatchery operations have raised important concerns regarding the efficacy and desirability of hatcheries as a primary mitigation tool (e.g., NRC 1995). The use of large scale hatchery programs and the hybridization between hatchery and wild stocks should be viewed with great concern (Hindar et al. 1991).

Recently, managers have suggested new roles for artificially propagated salmon which reflect the greater social and scientific concern for natural production and endangered stocks. Supplementation is one of those new roles and its purpose is to increase natural production while recognizing and minimizing potential genetic and ecological impacts (RASP 1992). Can that goal be achieved? In spite of many remaining questions salmon managers have already accepted supplementation and seem to have a lot of confidence in its potential. In fact, 50 percent of the increases in production computed from the system planning model are expected to come from supplementation or conventional hatcheries (RASP 1992). At least two of the major supplementation programs are receiving extensive evaluation - one in Idaho (e.g., Bowles and Leitzinger 1991) and the other in northeastern Oregon (e.g., Messmer et al. 1992).

2. Harvest

Major changes in the river harvest of Columbia River chinook salmon occurred during this period. The lowest recorded harvest since the fishery was established occurred in 1994 following a long decline in the number of fish entering the river. Three fisheries saw their last seasons: 1965, the last summer chinook season; 1977, the last spring chinook season; and 1988, the last sockeye season (ODFW and WDF 1993). These fishery closures and the overall trend in harvest (Figure 9) give a misleading picture of the production of chinook salmon in the basin between 1959 and the present because they only include the in-river harvest and the ocean harvest landed at Columbia River ports. As explained in the previous period, a significant percentage of the Columbia River salmon are harvested in the ocean and landed at distant ports. For example, the distribution of adult mortalities (1988B 1990 average) of fall chinook from Lyons Ferry Hatchery was estimated to be: 5 percent Alaska harvest; 2 1.7 percent British Columbia harvest; 12.6 percent Washington, Oregon and California ocean harvest; 28.6 percent Columbia River harvest; 17.3 percent interdam loss; 6.6 percent, Ice Harbor Trap; and 8.2 percent Lower Granite Dam escapement (CRITFC 1993 as displayed in Lestelle and Gilbertson 1993). The harvest management of Columbia River chinook salmon clearly has an international dimension which will not be covered here.

The shift from in-river to offshore commercial harvest continued the trend started in the previous period but that was not the only change in the fishing. Ocean and river sport fisheries which were not very large until after World War II, increased rapidly and by 1977, about one quarter of the combined ocean and river harvest was made by sport fishers (Gunsolus 1977).

Ocean fisheries and the growing sport fishery have taken away the dominance the river gillnet fisheries once enjoyed. The number of gillnet licenses declined and has held at about 850 for the past several years, however, the number of days open to commercial salmon fishing in the river below Bonneville Dam has steadily declined from 97 days in 1959 to 18 days in 1994). In 1994, the Youngs Bay fishery accounted for 81 percent of the commercial salmon landings below Bonneville Dam (ODFW and WDF 1995).

Harvest management has undergone major institutional changes. The 1974 decision by Judge Belloni, which extended to the Columbia River Judge Boldt's interpretation of in common (sharing equally the opportunity to take fish), permanently altered the institutional structure of salmon management in the river. Native Americans became an important part of salmon management which was formally recognized in the Columbia River Fish Management Plan.

3. Habitat

Construction of mainstem and tributary dams and the subsequent control to the river's hydrograph for the benefits of hydroelectric production, crop irrigation, flood control and transportion of goods created massive changes in salmon habitat in the mainstem Columbia and Snake rivers. The dams physically altered habitat by converting the free flowing river into slack-water reservoirs and altered the timing of natural flow events (Figure 14). Perhaps of equal importance were the indirect effects of the hydroelectric system. The cheap electricity produced by the system of dams and storage reservoirs was one of the factors that encouraged the rapid population growth in the northwest which increased pressure on salmon habitats throughout the region.

The conversion of a free flowing river to a series of reservoirs eliminated some of the more important spawning and rearing areas for chinook salmon in the basin. John Day Dam inundated extensive mainstem spawning areas for fall chinook (Fulton 1968). The current productivity of fall chinook in the Hanford Reach - the only remaining free flowing section of Columbia River accessible to salmon - is probably a conservative index of the historic productivity of the mainstem reaches.

Reservoirs also altered the rearing habitat for juvenile chinook salmon, especially the ocean type life history (juveniles that migrate to sea during their first year) and those stream type life histories (juveniles that migrate to sea in the spring of their second year) that over wintered in the mainstem. Subyearling chinook salmon spend more time rearing or migrating through the mainstem reservoirs than yearling smolts (Giorgi et al. 1994; Rondorf 1990 cited in Curet 1993). Extended rearing of subyearling chinook salmon is apparently a natural trait which has been observed in unimpounded rivers (Reimers 1973). However, in the altered habitat of the mainstem reservoirs, extended rearing is a detrimental trait because the juveniles are more vulnerable to predation by native and exotic fishes. High temperatures in the littoral areas of reservoirs can exclude the juvenile chinook salmon from their preferred habitat. Temperature may have a stronger influence than flows on the residence time in some reservoirs (Curet 1993), however, overall, the reservoirs have slowed the migration of all juvenile chinook salmon (Raymond 1988).

The life histories of juvenile chinook salmon are events that have to be described on both time and space scales. It's relatively easy to visualize changes in space - change from free flowing river to reservoir - and associate them with changes in the habitat of juvenile chinook salmon where specific parts of their life histories are carried out. Time is the more difficult scale to associate with life histories of the juveniles. The proper timing of life history events may be an important outcome of high quality physical habitat. The timing of juvenile migration to the sea is an important life history trait which shows less annual variability than, for example, adult abundance. The relatively low within-population variability in the timing of life history events

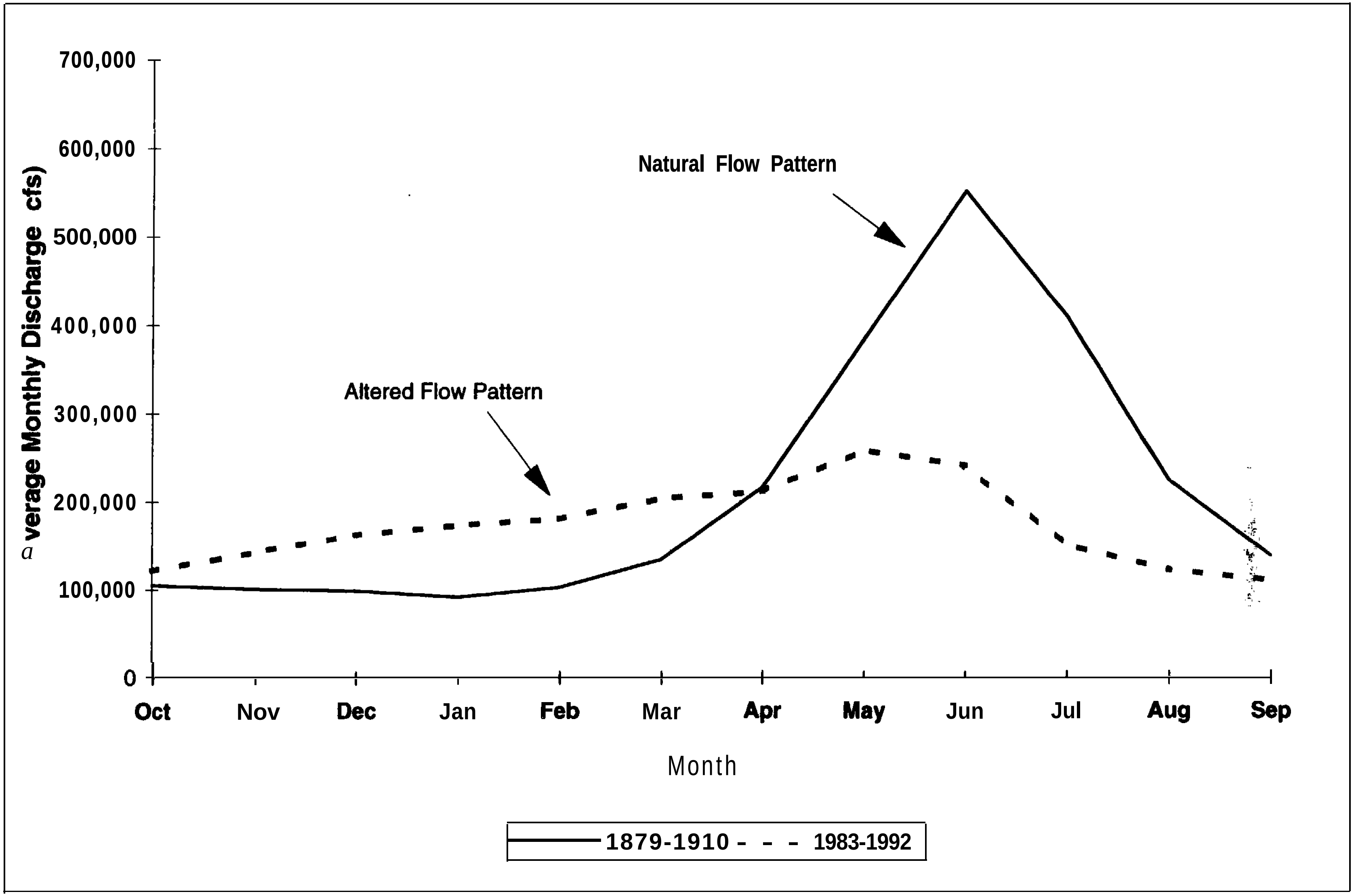


Figure 14. Change in monthly average flows for the periods 1879-1 910 and 1983-l 992 in the Columbia River at The Dalles, Oregon. (Source: Hydrosphere, Inc. 1990)

might suggest a strong selection pressure and indicate that the natural timing has survival value (Lichatowich and Cramer 1979). A change in flow patterns probably disrupted the timing of life history events tuned to seasonal patterns of the natural hydrograph. For example, the timing of downstream migration may respond to physiological changes in the fish and flow conditions in the subbasin and mainstem that ensure safe transport through the river and arrival in the estuary or ocean when food is abundant.

The effect of altered flow patterns may extend into the estuary and the near-shore oceanic environments. The impoundment of summer flows and their release during the winter (Figure 14) has altered coastal sea surface salinities from California to Alaska which may be an indication of other ecological changes in coastal ecosystems (Ebbesmeyer and Tangbom 1993).

Starting in the 19th century, there has been a cumulative loss of wetlands and shoreline habitat in the Columbia River estuary. Today, the surface area of the estuary is smaller and sedimentation levels have increased. The biologic community has changed from shallow water, benthic consumers to water-column pelagic and deep water, epibenthic consumers (Sherwood et al. 1990). While the effect of a century or more of change in the estuary on salmon production cannot be separated from over exploitation and changes in the upstream habitats, estuarine degradation has probably contributed to the declines of salmon, although the linkages have not been demonstrated

Biologists estimated that 50 percent of the prime spawning and rearing habitat in the Columbia Basin were lost prior to 1930 (OFC 1931), but the first published habitat surveys were not carried out until the late 1930s and 1940s. Those early surveys were used as baselines for another set of surveys carried out in the same streams a half-century later in 1990 to 1992 (McIntosh et al. 1994). The new surveys were carried out to determine if habitat had continued to decline after the initial surveys in the 1930s and 1940s.

Large pools are a critical habitat component for anadromous salmonids. They provide rearing habitat for juveniles and resting habitat for adult salmon and can also serve as refugia for both juveniles and adults during natural disturbances such as fires, winter icing and drought (McIntosh et al. 1994). When the streams were resurveyed, the frequency of large pools was one of the habitat components measured and compared to the earlier work. Streams in the mid-Columbia region (Yakima, Wenatchee and Methow) showed an increase in the frequency of large pools in the sampled stream reaches, which suggests habitat improved over the past 50 years. Unmanaged (wilderness) stream reaches in the mid-Columbia showed twice the improvement as managed streams. In contrast, the streams resurveyed in the Blue Mountain area (Tucannon, Asotin and Grande Ronde) of southeast Washington and northeastern Oregon showed decreases in the frequency of large pools. The exception in the Blue Mountains was the Tucannon River where large pools increased in frequency (McIntosh et al. 1994).

Both the Blue Mountains and mid-Columbia areas had a similar history of habitat degradation prior to 1930, but since then, development and habitat alteration in the two areas differed dramatically. The mid-Columbia has remained relatively isolated and undeveloped so salmon habitat had an opportunity to heal and improve. Timber harvest probably accounts for most of the difference between the managed and unmanaged (wilderness) areas in the mid-Columbia River. The Blue Mountains, which were on the main east-west trade and communications route developed to a greater degree after 1930, and as a consequence, salmon habitat continued to degrade. Although habitat has improved and some salmon populations are relatively healthy in the mid-Columbia subbasins, streams such as the Yakima and Tucannon experience lethal stream temperatures in summer which severely limit production (Lichatowich and Mobrand 1995; McIntosh et al. 1994).

C. MANAGEMENT FRAMEWORK

In 1960, after 90 years of hatchery operations, the search for a technological means of achieving a predictable and simple relationship between production and harvest was achieved, although it would be short-lived. Hatchery releases and coho harvest in the Oregon Production Index (OPI) in the 1960s provided the evidence mangers had been seeking for nearly 100 years. For about a decade there was an apparent simple relationship between the number of coho smolts released into the OPI and the harvest of those fish a year later (Figure 15). As smolt releases increased, the harvest of coho salmon in the OPI showed a corresponding increase. After 1970, adult production fluctuated widely, followed by the collapse of the fishery in 1977 in spite of increases in hatchery production. Although, biologists recognized that the improved harvest was associated with favorable ocean conditions, they chose to emphasize new hatchery technology as the explanation for the increase in production and harvest in the 1960s. Four years into the increase in production, managers believed that “The situation, while most encouraging, was not unplanned nor unexpected” (OFC 1964 p. 16). That statement is another example of the power of the management framework to shape the interpretation of information. The success of the hatchery program in the 1960s was in part due to improved disease control, the development of nutritious feeds and improved hatchery practices such as the release of full term smolts However, as events after 1976 showed, a major reason for the improved production was a change in ocean condition (Nickelson 1986).

The shift to smolt releases had a significant impact on the management framework. Since smolts were expected to migrate rapidly to the ocean, the release of smolts minimized the importance of the river except as a channel to transport smolts to the sea. It simplified the production system by circumventing the ecological restraints and bottlenecks in the river ecosystem. Adult production and harvest became a simple function of smolt releases. The goal that had eluded managers for a century had been achieved or so it was believed.

The river, even if it were relegated to the limited task of transporting hatchery smolts to the sea had to perform that task efficiently. In a production system that was gravitating towards human control and simplification through the use of hatchery smolts, increasing the number of smolts released became an important objective. Under that scenario, safe passage out of the river became the dominant problem (e.g., NPPC 1994; CBFWA 1991). Unlike the early 1900s when the fear of high mortalities during migration from the upper basin prompted the construction of Central Hatchery, the river now contained important new hazards to downstream migration in the form of mainstem dams. Safe passage for migrating smolts became a high priority program second only to artificial propagation. Habitat protection and restoration remained relegated to a minor role (Figure 16).

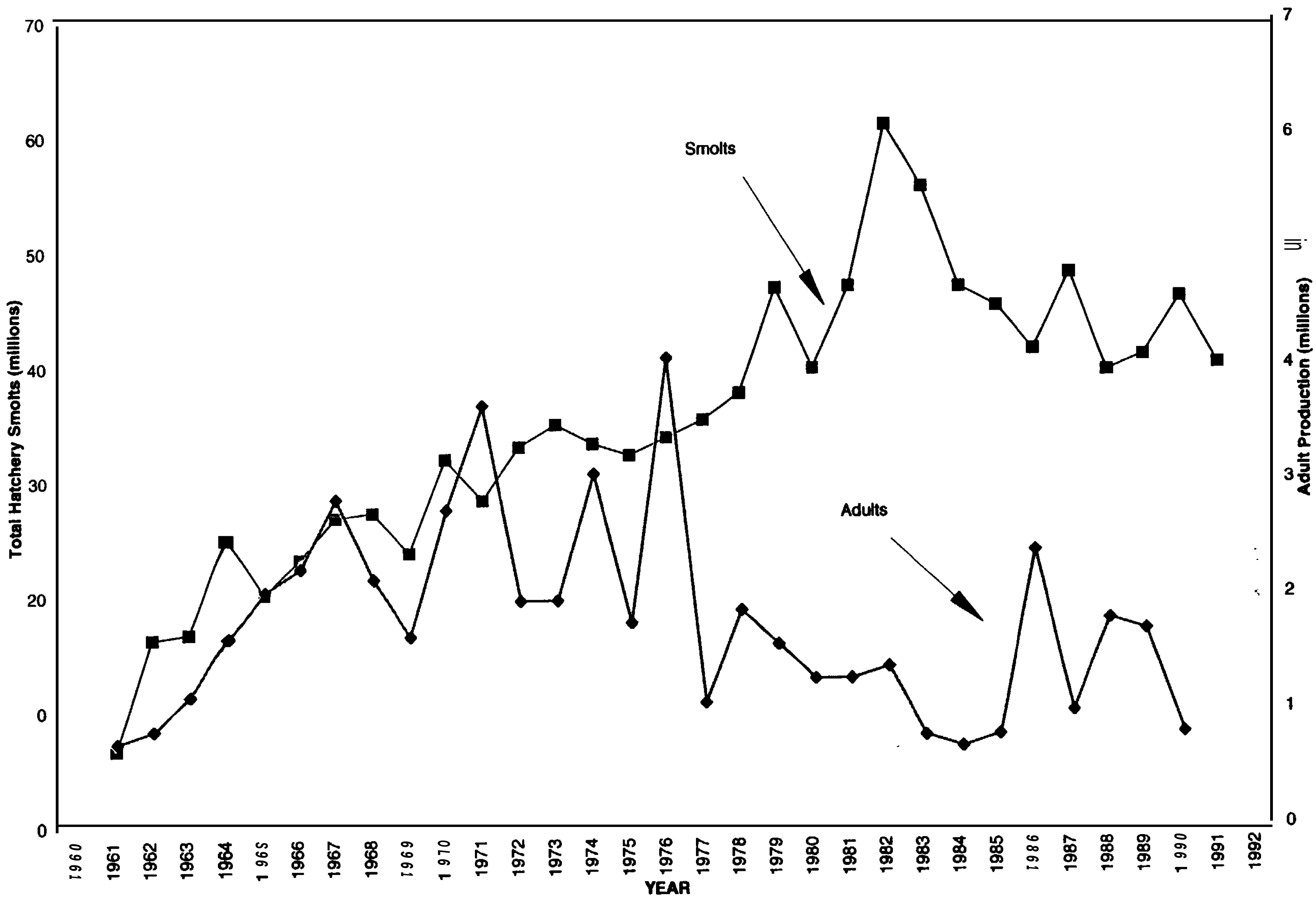


Figure 15. Release of coho salmon smolts and adult production in the Oregon Production Index area Smolt releases are adjusted to coincide with adult harvest of same broodyear.
(Source: Lichatowich and Nicholas in press)

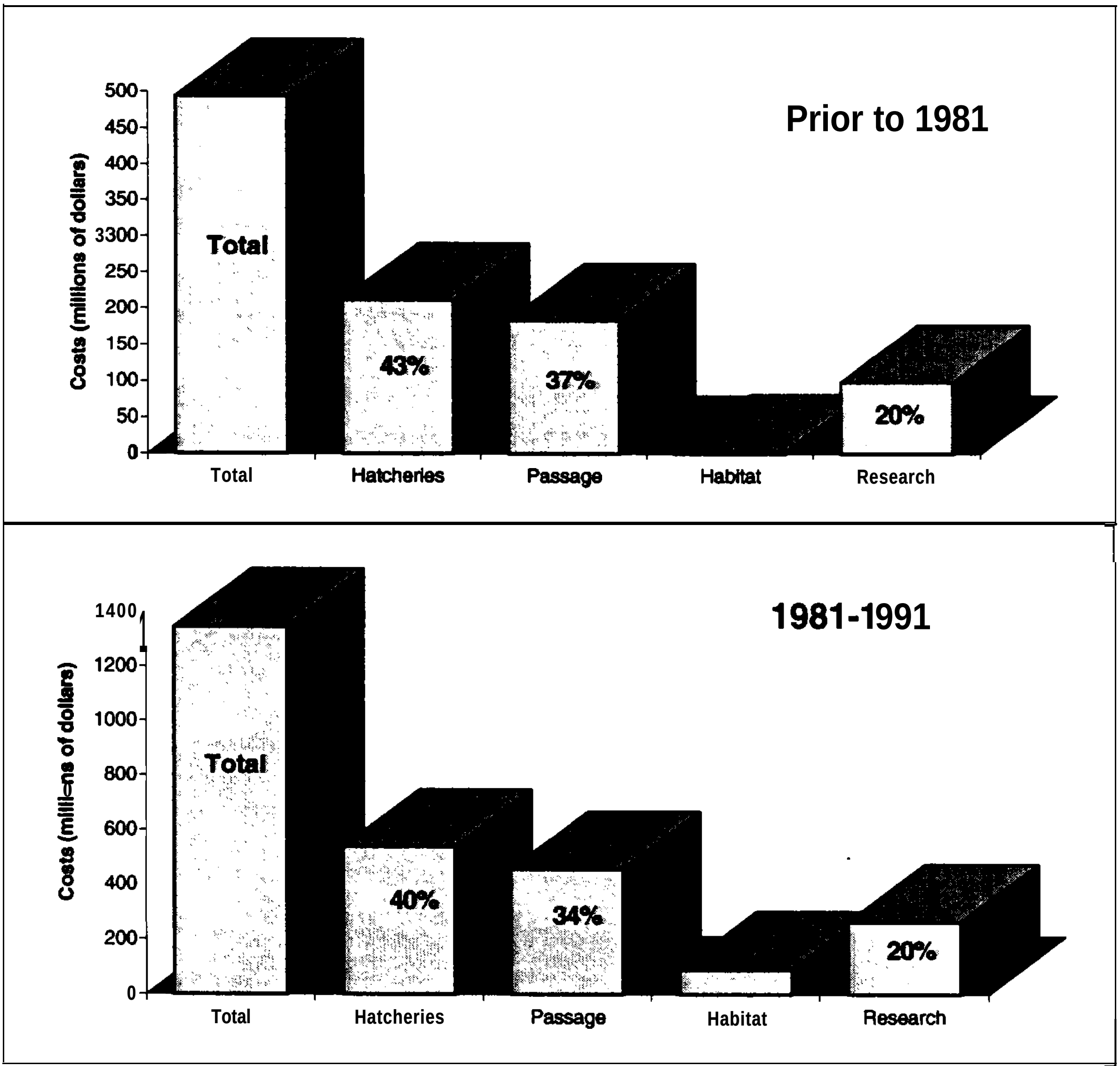


Figure 16. **Salmon protection costs prior to 1981 and from 1981 to 1991. (Source:** *GAO 7992)*

The statement above does not imply that emphasis on mainstem passage was merely an artifact of a management framework which assumed a simple relationship between hatchery smolts and adult abundance. After construction of the mainstem dams, adult and juvenile passage became a serious problem. On the other hand, the almost total neglect of habitat in the subbasins (measured by expenditures) was consistent with and a product of a management framework which envisioned a highly controlled production system based on artificial propagation; a management framework that relegated rivers to the status of conduits for transporting hatchery smolts to sea. In many of the subbasins, habitat continued a century-long pattern of decline. The cumulative effects of habitat degradation is most visible in the lower mainstems of the subbasins which have been rendered lethal to salmon during significant parts of the year (Table 4).

Table 4. Habitat suitability for juvenile chinook salmon in the lower reaches of selected subbasins. (Source: Lichatowich and Mobrand 1995)

Subbasin	*Comments on Habitat*	*Source*
Yakima	Lower river below Prosser (RM 47.1) frequently exceeds 75°F and occasionally reaches 80°F in July and August rendering the lower river uninhabitable by salmonids.	CTYIN et al. 1990
Tucannon	Water temperatures in lower river at or above lethal levels.	WDF et al. 1990
Umatilla	Lower 32 miles subject to irrigation depleted flows and temperatures exceeding upper lethal limits for salmonids.	CTUIR and ODFW 1990
John Day	Juvenile chinook salmon generally not found in the river where temperatures reach 68°F. High stream temperature eliminates juvenile rearing habitat in the lower river.	Lindsay et al. 1981; ODFW et al. I990
Deschutes	In the mainstem Deschutes River, summer temperatures are adequate for chinook salmon. However, there are temperature problems in the lower reaches of the tributaries where spring chinook salmon spawn. In addition Ceratomyxa shasta limit the survival of juvenile chinook salmon in the mainstem through the summer months.	Ratliff 1981; ODFW and CTWSR 1990

With regard to mainstem passage, problem definition and solutions are consistent with a framework that assumes a simple relationship between artificial propagation and production and a management framework that viewed the river as a conduit for transporting hatchery smolts to sea. Research on passage problems is largely a search for a flow-survival relationship which will permit managers to control flows and water velocity to facilitate smolt movement down the river conduit. The ecological value of the mainstem as well as stock and life history diversity in relation to flows and migration have largely been ignored (but see Giorgi et al. 1994 for an exception).

In recent years, the efficacy of artificial propagation has been questioned (Hilbom 1992; NRC 1995; White 1995) and the role of hatcheries in the decline of salmon is being recognized (Flagg et al. 1995 and Reisenbichler, personal communication). The Endangered Species Act forced greater concern for and attention to topics such as biodiversity, interactions between hatchery and wild salmon and the importance of natural production. Implementation of the act also forced the basin to reconsider the success and failures of the hatchery program.

The old management framework has not been displaced. There is still strong acceptance of the simple relationship between smolts released and adult production (Whitney et al. 1992) and scientists continue to support the existing framework in spite of its deficiencies (e.g., Cuenco 1994). However, what appears to be a new framework is emerging. The recent emphasis on ecosystem management is a recognition of failure of the existing management framework - a failure to adequately solve the problems, reverse the declines and bring about a recovery (Lichatowich 1996). The region is in the midst of a transition, though which way it will proceed is uncertain. Consider the Council's Fish and Wildlife Program. In the latest version of the program (NPPC 1994) there is an important shift in approach which emphasizes ecosystem health. The salmon and steelhead goal also recognizes the changing framework by accepting a dual goal of doubling the run without loss of biodiversity. While the policy and goals of the Fish and Wildlife Program reflect an emerging shift in the management framework, the specific measures in the program appear to be firmly anchored to the status quo. In Section 7 of the program (Salmon Production and Habitat) there are 93 measures that address artificial propagation whereas only two measures in the same section directly address the subject of biodiversity. Implementation strategies may increase the disparity between artificial propagation and natural production measures in the fish and wildlife program. Many of the measures that benefit natural production have not been implemented (personal communication Bill Bakke, Native Fish Society, Portland, OR).

Managers are calling for changes in the hatchery program in recognition of the changing social and scientific environment and the emerging ecosystem perspective as an alternative to the existing management framework. Managers are beginning to recognize the need to integrate artificial propagation into the total production system of a watershed (Lichatowich and McIntyre 1987; RASP 1992). Supplementation appears to be the primary vehicle for achieving that integration. Supplementation is the use of artificial propagation not to replace but to enhance or restore natural production. While there are guidelines for the use of supplementation (CBFWA 1991; RASP 1992), it will need extensive evaluation before it can be considered a reliable tool. It appears to be a widely accepted fact among managers that the role of artificial propagation is changing (Flagg et al. 1995; Gladson 1990; RASP 1992; White et al. 1995) The critical question now is what kind of change will be considered sufficient? Will the change be a superficial renaming of hatchery activities while retaining the same assumptions and framework, i.e., a framework based on the control and simplification of the production system and an assumption of a simple relationship between juveniles released and adult returns?; Will the new framework continue to attempt to circumvent the ecological processes, or will the change involve a fundamental shift in the framework, a shift that incorporates an ecosystem perspective?.

D. SUMMARY

Status The average harvest of chinook salmon dropped to five million pounds, although that figure does not include troll caught fish landed outside the basin. The Snake River sockeye and chinook salmon were listed under the federal Endangered Species Act. Development of the basin's water resources was completed and natural flow patterns were altered. Habitat in many subbasins continued to decline.

Response The full development of the hydro system was met with a massive increase in artificial propagation. Several in-river fisheries were closed and the commercial season was significantly reduced. Scientific research continued to show the importance of the salmon's stock structure and identified artificial propagation as contributing to the decline of natural production. The Northwest Power Planning Council recognized the importance of biodiversity and natural production in its Fish and Wildlife Program.

Management Framework In spite of a long history of persistent decline, failures to reverse those declines in chinook salmon production and scientific evidence questioning the management framework, the basic assumption that control and a simplification of the production system could restore salmon production remained intact.

VI. DISCUSSION

In the introduction, management framework was defined as the set of principles, concepts and assumptions that guide the choice and implementation of research and management activities. Management framework as it is used in this report is similar to Kuhn's (1970) use of the term paradigm and according to Kuhn (1970), a paradigm gains and retains status because it is more useful than its competitors in solving problems. When a management framework is no longer effective one of its competitors should replace it. Kuhn's observation only applies, however, if the scientific community determines if the prevailing paradigm is effective in solving important problems or if it recognizes the existence of a crisis in their management. Through most of the last century the management framework was based on concepts and assumptions that naturally led to a reliance on artificial propagation, and through most of their history, hatcheries were assumed to be successful. Scientific evaluations were not carried out until recently and those did not address all the important questions. Willis Rich and others pointed out the shortcomings of the existing framework in the 1930s and 194Os, but they failed to bring about a change. Early recognition of the failure of the prevailing framework may have been overridden by social and economic pressures that left artificial propagation as the primary, albeit not very reliable, management strategy to mitigate the basin's development. Under those circumstances, hatcheries and the underlying framework that justified them may have been retained as much to solve a public perception problem - to show that salmon and dams were compatible - as to meet a biological need.

This report focused on artificial propagation because it was the first management tool and it has dominated management through its 120 year history. The regulation of harvest began shortly after the first hatcheries. Habitat surveys did not begin until 1938, and habitat protection and restoration has not been a high priority since then, at least not as high a priority as artificial propagation. All areas of management - harvest, habitat and hatcheries q were influenced by the prevailing framework. Had this report focused on harvest or habitat, the overall message would have been the same.

There were several crossroads in salmon management over the last 120 years when a different decision might have led to a better outcome for the Pacific salmon in the Columbia River (Table 5). The future cannot be predicted with any real certainty, but there definitely have been missed opportunities. If a biologist had been stationed at the Baird Hatchery, it might not have taken until the 1920s to recognize that hatchery operations needed a scientific basis. If the biologist sent to Baird Hatchery had come from the same educational background that produced Charles Gilbert, Willis Rich or W.F. Thompson, the effective integration of artificial and natural production might have been advanced by several decades, something that is yet to occur. It is interesting to speculate about the possibilities if the unit of management had changed to the watershed instead of aggregated stocks, if an independent commission had taken over management and research or if the emerging new framework of the 1940s had been given a chance to survive (Table 5). Although it's important to understand that opportunities were lost, speculation about missed opportunities won't change the status of the salmon in the Columbia River today. It is more important to recognize that the basic features of the management framework have not changed in 120 years and that they have not been successful in solving

Table 5. **Important crossroads in the history of salmon management in the Columbia Basin. The events represent points where a diierent decision might have set salmon management and the sahnon on a trajectory for a different future.**

Date	Event	outcome
1879	Livingston Stone requests that a biologist be stationed at the Baird Hatchery, California	Request was denied. If hatcheries had been directly linked to ecological and life history studies of the salmon, those studies might have lead to early recognition of the destructive nature of artificial propagation particularly prior to 1940s. Studies might have exposed the myth that artificial propagation could replace lost habitat as false while significant blocks of habitat still remained.
1925	International Pacific Salmon Investigation Federation recommended using the watershed as the basic management unit for Pacific salmon.	Largely ignored until rediscovered as part of ecosystem management in recent decades. If watersheds were the basic management unit, the stock structure and the importance of ecosystem processes might have received earlier recognition.
1938	The Oregon State Planning Board recommends a study of the use of salmon refuges and the establishment of an independent fisheries commission to regulate harvest and direct research in the Columbia River.	The interstate commission was not implemented. Pacific salmon management and research remained fragmented among several state and federal agencies. A strong interstate commission could have helped protect salmon during the development of the Columbia River basin in the same way that the International Pacific Salmon Fisheries Commission protected salmon habitat in the Fraser River.
1943	The Washington State Senate (Columbia River Interim Investigation Committee) also recommended a unified and independent commission charged with the management of the Pacific salmon in the Columbia River.	Similar to above
Crica I946	By the mid- 194Os, understanding of the biology and stock structure of Pacific salmon had developed to the point that a new framework was emerging (e.g.. Rich 1935, 1939, 1940; Craig 1935).	Although a management framework based on the stock structure for Pacific salmon was adopted by the International North Pacific Salmon Commission for Fraser River, the lower Columbia River development program failed to incorporate that information and instead worked within a framework based on the status quo. This may have been the most important crossroad for Pacific salmon. Failure to adopt a different approach probably led to the endangered species listing.
1990s	Intensive efforts to restore the salmon using the old framework have failed to show results.	To be determined.

problems and preventing the present crisis. It's more important to recognize the need for a new management framework.

Almost from the beginning of the intensive commercial harvest of chinook salmon in the Columbia River, fisheries managers relied on the belief that technology in the form of artificial propagation would maintain the supply of salmon. Hatcheries appealed to beliefs and values that were rooted deep in our culture and science. In the mid- 19th century, ecosystems and natural resources were viewed differently than today. Ecosystems were warehouses where resource commodities were stored for man's use (Worster 1977). The human mission was to tame the wilderness and gain control over its resources (Bottom in press; White 1967) The salmon had to be protected from the savagery of natural uncontrolled rivers. Hatcheries were refugia from the savage wilderness of natural rivers, the place where humans could protect salmon from nature and at the same time control the supply. Through hatcheries, salmon could be brought into the cultivated garden of civilization where they would serve humans as they were intended (Bottom in press). Artificial propagation's roots were so deep in our culture that salmon managers were able to maintain optimistic support for hatcheries for 90 years (1879- 1960) even though they showed little evidence of success over that period. Failure to produce results or solve the problem of declining production were not enough to change the framework.

While the basic appeal of artificial propagation was rooted deep in our culture, hatchery programs did undergo superficial changes over the past 120 years to maintain consistency with the changing social and scientific beliefs and attitudes. In this review of the role of hatcheries in salmon management four phases in the continuum of change can be identified. They are stated here in terms of expectations: 1) Artificial propagation would control production and increase it to the point that restrictions on harvest would be unnecessary; 2) Tbe progressive view of conservation led to the belief that hatcheries could be designed to achieve maximum efficiency in the production and management of salmon; 3) Hatcheries were designed like factories to lit the machine models of engineered systems following World War II. With the widespread adoption of long-term tearing and the release of smolts, the freshwater phase of the life cycle was circumvented (except for migration to and from the sea); and 4) More recently artificial propagation has been viewed as a means of furthering ecosystem management (conservation hatcheries) and the protection of endangered stocks of salmon.

Originally, hatcheries were viewed as an alternative to natural production, and harvest regulation. Through artificial propagation, the huge surplus of eggs deposited in the gravel by the natural spawning runs would be converted to adult salmon. Hatcheries allowed managers to simplify and control the relationship between salmon production and harvest. Because they offered the expectation of unlimited exploitation while still maintaining the supply of salmon, hatcheries were consistent with and highly supportive of the prevailing community values which promoted a laissez-faire attitude towards the exploitation of natural resources.

Shortly after the turn of the century government leaders such as Theodore Roosevelt challenged the laissez-faire access to natural resources. The Progressives viewed conservation and natural resource management as a centralized technical/scientific process by which government technicians allocated and managed resources to achieve tbe highest and best economic use. The Progressives stressed the use of resources, but the way resources were used had to represent the most efficient way to achieve the highest economic benefit to the nation. Central Hatchery, constructed in 1909, illustrates the influence of progressive thinking on hatchery operations and the adaptation of hatchery operations to the prevailing set of community values. Central hatchery was a large facility capable of handling 60 million eggs. It was designed to achieve the economies of scale of a centralized factory and to make salmon production more efficient by transferring eggs from the upper river and releasing juveniles in the lower river thereby circumventing the dangerous downstream migration. Central Hatchery also served as a clearinghouse for eggs which were shipped throughout the region to keep the ponds full in hatcheries throughout the region. Artificial propagation fit the Progressives ideal of efficiency, highest use and centralized control by experts.

The Progressives introduced science to resource management. A shift in hatchery management which emphasized the economic principles of supply and demand was a natural extension of the Progressive philosophy and the incorporation of science into resource management (Bottom in press). The best example of this approach was the catchable trout program. The rearing of salmon and steelhead to full term smolts before release from the hatchery was the anadromous equivalent to the catchable trout program. The shift in hatchery practices to predominantly smolt releases did more than increase their survival to the adult. It circumvented the ecological complexities of natural production and permitted the managers to treat the river as a simple conduit for the transport of smolts to the ocean. The release of smolts simplified the relationship between production and harvest, and circumvented the freshwater phases of the salmon’s life cycle, the ecology of the natural river became irrelevant.

Because hatcheries circumvented the freshwater part of the salmon’s life cycle, they were the ideal choice to mitigate the effects of large scale, federal watershed developments during the 1930s and beyond. The model for the massive development of the Columbia Basin was the machine which reflected an emphasis on systems engineering that was popular after the second world war.

Artificial propagation easily shifted into a machine vision for the river. The loss of salmon habitat was mitigated by the development of a massive hatchery program. With the construction of mainstem dams, however, the river was no longer a safe conduit for the transport of smolts to the sea. The simple relationship between smolts released and harvest was complicated by the effects of passage through or around the turbines and the series of reservoirs created by the dams. Development of safe passage through the mainstem became a primary emphasis of managers and research on mainstem survival achieved co-dominant status with artificial propagation (Figure 16). But like the hatcheries, passage activities were based on simplifying assumptions, by the search for a silver bullet, a technological solution. The ecological value of the river and the biological diversity of the salmon got lost among transport barges, fliplips, fish guidance mechanisms, migration models and designer flows. Technology will always be an essential part of the management of Pacific salmon in the Columbia River, but technology that ignores the rich biodiversity of the chinook salmon expressed, for example, in multiple life history patterns (e. g. Lichatowich and Mobrand 1995), and ignores the natural ecological process of the river that the salmon have adapted to has not and will not prevent continued depletion.

The introduction of science into fisheries management as part of the early conservation movement stimulated the implementation of several investigations of the life history and biology of Pacific salmon. After several decades, the information obtained from those investigations led scientists to question the use of hatcheries as the predominant tool in the restoration and management of salmon (NRC 1995). Research has improved understanding of the production process in Pacific salmon and given rise to a greater awareness of the importance of natural production, biodiversity within and between the salmon populations and healthy riverine habitat. Improved scientific understanding and persistent depletion of the salmon led to a change in community values which are exemplified by environmental legislation including the Endangered Species Act. Consistent with this shift, hatcheries have developed new terminology and expectations. An example of the new terminology is the conservation hatchery which is an attempt to shift the image of artificial propagation so it is more compatible with current emphasis on natural production and biodiversity. In this new role, hatcheries are expected to supplement streams and increase or rebuild natural production rather than replace it (Flagg et al. 1995).

Captive brood programs, which hold the salmon in the hatchery throughout their entire life cycle, are being used to aid the recovery of threatened or endangered stocks of salmon. The captive brood programs can be viewed as the latest in a long series of steps taken to circumvent the salmon's natural habitat. The release of sac fry circumvented egg mortality: the release of fingerlings circumvented predation on fry; the release of smolts circumvented degraded habitat and most of the freshwater life cycle; and captive broodstocks prevents any contact with the natural environment. Captive broodstock technology achieves the total control over salmon production that George Brown Goode talked about in the late 19th century.

Throughout their history, hatchery programs have been implemented under the assumption that relationships among reproduction, production and harvest could through human intervention be simplified, controlled and made more predictable. Production has been simplified and brought under human control in that 80 percent of the adult salmon returning to the Columbia River are a product of the basin's hatchery program. However, achieving that degree of control and simplification has come at a high price. Artificial propagation has not maintained the production and productivity of the salmon in the Columbia River.

Clearly there is a need for a new management framework. There are signs that a new framework is emerging from the crisis-level depletion of Pacific salmon. The basic assumptions of the emerging framework appear to be diametrically opposed to those underlying the current paradigm:

- Restoration and protection of natural ecological processes vs the circumvention of those processes;

- Controlling human behaviors that limit or destroy ecological processes vs. the attempt to control and improve nature; and

- Promoting biological and habitat diversity vs. simplifying the production process in the act of improving it.

The hatchery program was implemented within a management framework that viewed the production process as something that needed to be simplified and controlled and viewed the river and its habitat as something to be circumvented. *Thatframework. which arguably is largely intact, contributed to the loss of natural productivity in the basin.*

The hatchery program has a legitimate role in the Columbia Basin, but that role will have to be based on a new set of assumptions and concepts. The old concepts and assumptions regarding simplification, control and independence from the river ecosystem need to be discarded. Throughout its history in the Columbia Basin, the hatchery program has exhibited a chameleonic behavior, changing superficially to match the social and scientific environment while retaining the same fundamental conceptual framework. That framework or paradigm has not been successful in solving the overriding problem of continuing salmon depletion. A new more effective framework may emerge and there are signs that such a transition is taking place. Whether or not the politics of salmon restoration will permit fundamental changes in the management framework remains to be seen.

The current status of Pacific salmon in the Columbia Basin is not what salmon managers intended to achieve. Salmon managers, culturists and researchers were a hard working group of professionals dedicated to maintaining the “supply” of salmon. Given those good intentions, How did reality deviate so far from expectations? A major part of the answer to that question is found in the framework, the set of assumptions and principles that made up management’s underlying foundation. The framework which was so taken for granted that it was rarely referred to or discussed, turned out to be a major determinant of the salmon’s future. However, it was not only salmon management that suffered under an inadequate framework.

Perhaps William Cronon described the situation best in his foreword to Susan Langston’s book on forest management in the Blue Mountains (Langston 1995).

> ***“The problems that foresters faced in the Blue Mountains flowed as much from their own scientific paradigms as from the ecological phenomena going on in the forest itself - phenomena that those paradigms sometimes rendered all too invisible. The moral of this story should be clear. Even well-intentioned management can have disastrous consequences if it is predicated on the wrong assumption, and yet testing those assumptions is always much harder than people realize. To do so, we must realize that ecosystems are profoundly historical, meaning that they exist in time and are the products as much of their own past as of the timelessly abstract processes we think we see going on in them.”***

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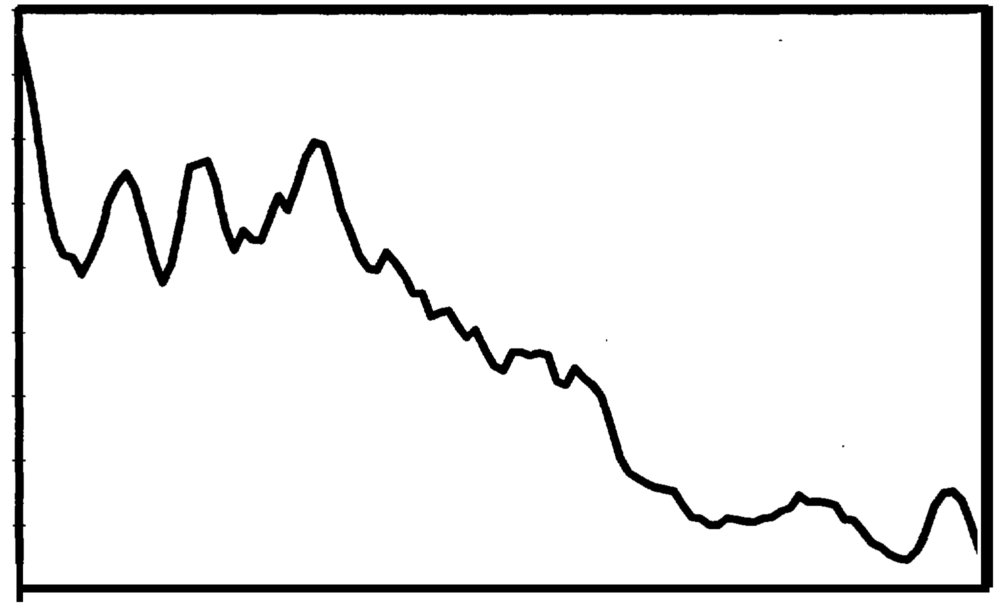

Chinook Salmon (Oncorhynchus tschawytscha) in the Columbia River: The Components of Decline

May 1996

Prepared by

James A. Lichatowich
Lars E. Mobrand

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CHINOOK SALMON *(ONCORHYNCHUS TSHAWYTSCHA)* IN THE COLUMBIA RIVER: THE COMPONENTS OF DECLINE

INTRODUCTION

The objective of this paper is to review the patterns of abundance of chinook salmon (Oncorhynchus tshawytscha) in the Columbia River and discuss the factors contributing to the decline. Two geographical scales are considered: one is a basinwide (including ocean) review of chinook salmon abundance, habitat quality and climate change; and the second is a more focused analysis of changes in the abundance of chinook salmon in streams flowing through the steppe and shrub-steppe vegetation zone (Figure 1) which lies in the rainshadow of the Cascade Mountains and includes the Yakima, Tucannon, Umatilla, John Day and Deschutes subbasins.

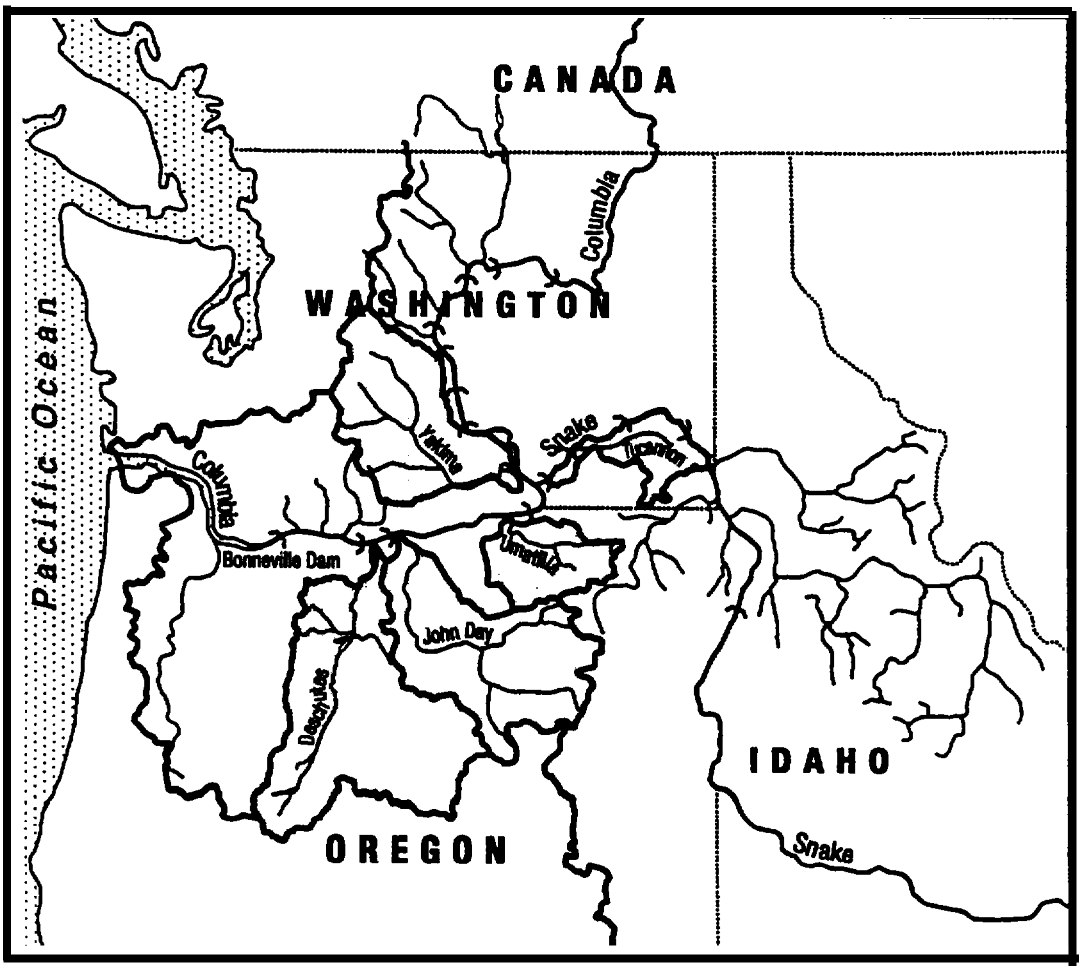

Figure 1. The Columbia River Basin. The rivers flowing through the steppe and steppe-shrub zone are shown in the stippled area. A - Deschutes, B- John Day, C - Umatilla, D - Tucannon, and E - Yakima rivers.

Prior to the basin's development, 4.7 to 9.2 million chinook salmon entered the river each year (Northwest Power Planning Council (NPPC) 1986), however, between 1985 and 1992 an average of 840,000 wild and hatchery chinook salmon entered the river (Oregon Department of Fish and Wildlife (ODFW) & Washington Department of Fisheries (WDF) 1993). Depletion is the result of excessive harvest, habitat degradation, poor hatchery practices and the construction and operation of dams in the mainstem and tributaries.

For about 50 years, since the initiation of the Lower Columbia River Development Program, extensive restoration programs have attempted to rebuild salmon populations in the Columbia Basin (Laythe 1948). Fishery managers have closely linked the lack of recovery to the development and operation of an extensive hydropower system which kills juvenile and adult salmon at mainstem dams, inundates spawning and rearing habitat and significantly alters mainstem flow patterns (e.g. Columbia Basin Fish and Wildlife Authority (CBFWA) 1991; NPPC 1994). In addition, for nearly a century, the region has attempted to circumvent problems created by habitat degradation and overharvest through the use of artificial propagation. The priority given to artificial propagation and mainstem passage is reflected in the way restoration budgets are allocated (Figure 2).

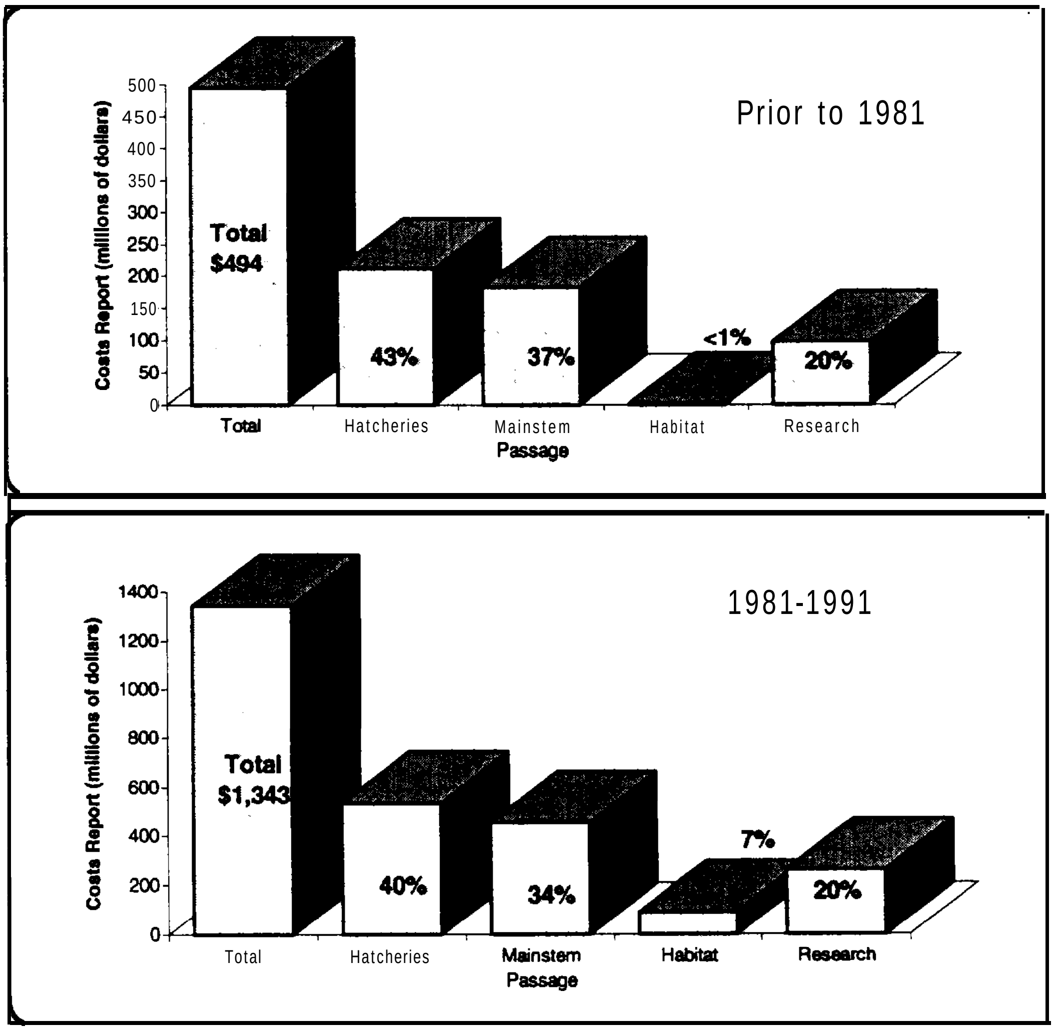

Figure 2. Salmon protection costs prior to 1981 and from 1981 to 1991. (Source: *GAO 1992)*

Mainstem dams began impounding water in the Columbia River in 1933 with the construction of Rock Island Dam. In 1938 and 194 1 construction of the Bonneville and Grand Coulee dams was completed. The dams had major detrimental impacts on juvenile and adult salmon. However, the chinook salmon as well as other species were already in decline before the first mainstem dams were built (Lichatowich in press).

By 1930, the Oregon Fish Commission (OFC) (1933) estimated that 50 percent of the best spawning and rearing habitat for salmon in the basin had been lost. Clearly, the factors leading to the current status of chinook salmon are complex and involve more than the construction of mainstem dams.

The paper is divided into five parts: 1) harvest and decline of chinook salmon in the Columbia River; 2) natural fluctuations in salmon production; 3) habitat degradation; 4) changes in life history patterns of chinook salmon; and 5) discussion and implications.

HARVEST AND DECLINE OF CHINOOK SALMON IN THE COLUMBIA RIVER

A Brief History of the Fishery

The commercial harvest and export of salted salmon in the Columbia River began in the 1820s and grew modestly to 2,000 barrels by the early 1860s. Intensive fisheries did not begin until cannery technology reached the Columbia River in 1866, after which the catch of salmon increased rapidly (Craig & Hacker 1940). For canning purposes, chinook salmon always brought the highest price (DeLoach 1939) and the fish that entered the river in spring and early summer were of highest quality (Craig & Hacker 1940). The harvest of chinook salmon peaked in 1883 at 19,413 metric tons (Beiningen 1976). The harvest of salmon (all species) in the Columbia River by Native Americans prior to contact with Euroamericans was about 19,000 metric tons (Schalk 1986) which approximated the peak commercial harvest of all salmon of 22,200 metric tons (Beiningen 1976).

In the early years of the commercial fishery, the harvest of salmon took place after they entered the river, principally by gillnets, but fixed traps and seines were also used in the lower river, and fishwheels were used in the river above the present site of Bonneville Dam.

The fishery was intense. By 1895, there were 2,207 gillnets, 378 traps, 84 haul seines and 57 fishwheels harvesting salmon in the river (Smith 1979). In 1895, McDonald (1895) noted that surveys by the U. S. Fish Commission had shown a significant reduction in the number of salmon reaching the headwaters of the Columbia and Snake rivers. After the turn of the century, the sail powered gillnetters were fitted with gasoline engines which added to their fishing power. In addition, by 1920, the off shore troll fleet had grown dramatically. At the same time the harvest of chinook salmon was beginning a major period of decline.

Patterns of Abundance

The harvest of chinook salmon can be divided into four phases: 1) Initial development of the fishery (1866B 1888); 2) a period of sustained harvest with an average annual catch of about 11,000 metric tons (1889B 1922); 3) resource decline with an average annual harvest of 6,800 metric tons (1923B 1958); and 4) severe depletion with an annual average harvest of about 2,200 metric tons (1958 to the present) (Figure 3). Recent declines may indicate the system is slipping to a new, even lower level of productivity.

Figure 3. Five year running average of chinook salmon harvest in the Columbia River (1866 to 1992). *(Source: Beiningen 1976; ODFW & WDF 2993)*

Qualitative Changes in the Fishery

The fishery harvested three races of chinook salmon which entered the river in the spring, summer or fall. Between 1892 and 1920, the fishery enjoyed a **period** of **apparent** stability in the total harvest (Figure 3). However relative abundance of the three races of chinook salmon in the Columbia River underwent important qualitative changes as the fishery shifted from the spring and summer to the fall run fish. Fishermen targeted the spring and summer fish because they made the highest quality canned product and brought the highest prices (DeLoach 1939). Therefore, the declining catch of those races reflected real declines in abundance rather than a shift in fisherman preference. As spring chinook declined, the total quantity of harvested fish was maintained by a qualitative shift in the fishery from the spring/summer to fall chinook salmon (Figure 4). In 1892,95 percent of the chinook salmon harvest was taken from the spring and summer run. By 19 12,75 percent of the harvest was composed of spring or summer run fish as more fall chinook were harvested, and in 1920, fall chinook salmon made up 50 percent of the catch (Smith 1979). Although the harvest of all races of chinook salmon underwent rapid decline after 1923 (Figure 3), the decline in the spring and summer races started much earlier. Craig and Hacker (1940) suggested it started by 1911 or even earlier.

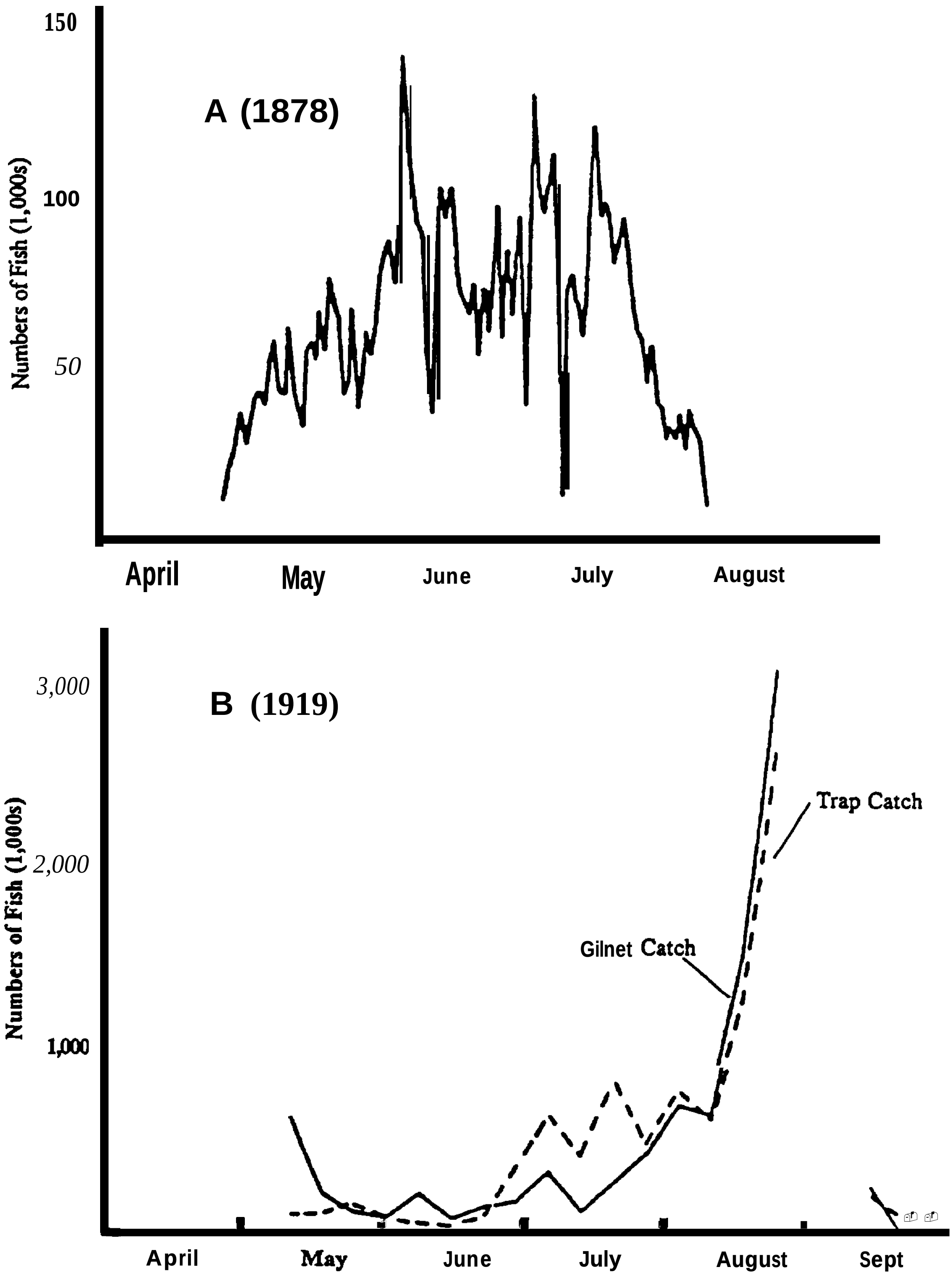

Figure 4. **Comparison of the seasonal distribution of the chinook harvest in the Columbia River in 1878 (A) and 1919 (B). (Source: Whitney** *and White 1984)*

The chinook salmon entering the Columbia River experienced two other qualitative changes. A decline in the size and age of chinook salmon has been observed in populations entering rivers from Alaska to California. In the Columbia River, smaller and younger chinook salmon probably resulted from selective harvest and habitat degradation (Ricker 1980). Another qualitative change began in the late 1950s when the development of more nutritious feeds and better disease treatments apparently increased the survival of artificially propagated salmon (Lichatowich and Nicholas in press). Hatchery fish now make up about 80 percent of the salmon returning to the Columbia River (NPPC 1992).

Change in Abundance in Tributary Streams

Many watersheds were degraded in the late 19th and early 20th centuries. Unfortunately, in the late 1800s biological surveys and monitoring were practically nonexistent. In fact, few scientific surveys or research were conducted prior to the 1930s or 1940s (Crutchfield & Pontecorvo 1969). The Yakima River is the only stream in the steppe and shrub-steppe zone for which predevelopment estimates of the chinook salmon run is available. Prior to development, 250,000 spring chinook entered the Yakima River each year (Smoker 1956 cited in Fast et al. 1991). By 1900, the run had declined by 90 percent. Since 1957, the number of adult spring chinook entering the Yakima River has ranged from 854 to 12,665 fish (Fast et al. 1991). From 1983 to 1989, the fall chinook run has ranged from 757 to 4,400 fish (CTYIN et al. 1990).

Estimates of predevelopment abundance of chinook salmon in the other subbasins do not exist, however, anecdotal evidence suggest that the populations were much larger than they are today (Lichatowich and Mobrand 1995). In recent years 16 to 59 fall chinook redds have been counted in the lower Tucannon River. In addition, the Tucannon River supports a spring chinook run of 200 fish (WDF et al. 1990). A range of 1,290 to 3,895 spring chinook and 5,219 to 12,254 fall chinook salmon enter the Deschutes River (ODFW and CTWSR 1990). From 1978 to 1985, the escapement of spring chinook salmon into the John Day River ranged from 918 to 1,923 spring chinook (Lindsay et al. 1986). About 100 fall chinook spawn in the John Day River (Olsen et al. 1992). The reintroduction of spring chinook into the Umatilla River was recently initiated.

NATURAL FLUCTUATIONS IN SALMON PRODUCTION

Climate Patterns and Salmon Abundance

Climate and fisheries productivity in the northeast Pacific fluctuate on a decadal scale which at least partially explains the pattern of chinook salmon harvest shown in Figure 3 (Beamish and Bouillon 1993; Nickelson 1986; Ware and Thomson 1991).

Evidence for a linkage between changing ocean productivity and salmon production comes from a 200 year record of standing stocks of pelagic fishes in the California Current (hake, Merluccius ***productus;*** sardine, ***Sardinops sagax;*** and anchovy, ***Engraulis mordax).*** Historical standing stocks were reconstructed from scales contained in core samples taken from anaerobic sediments (Smith 1978; Soutar and Isaacs 1974) (Figure 5). Those data contain two features relevant to this paper: 1) A 200 year peak in standing stocks near the turn of the century; and 2) 200 year low in standing stocks in the 1930s and 1940s. After the initial development of the fishery, the harvest of chinook salmon in the Columbia River generally followed the trend in marine standing stocks

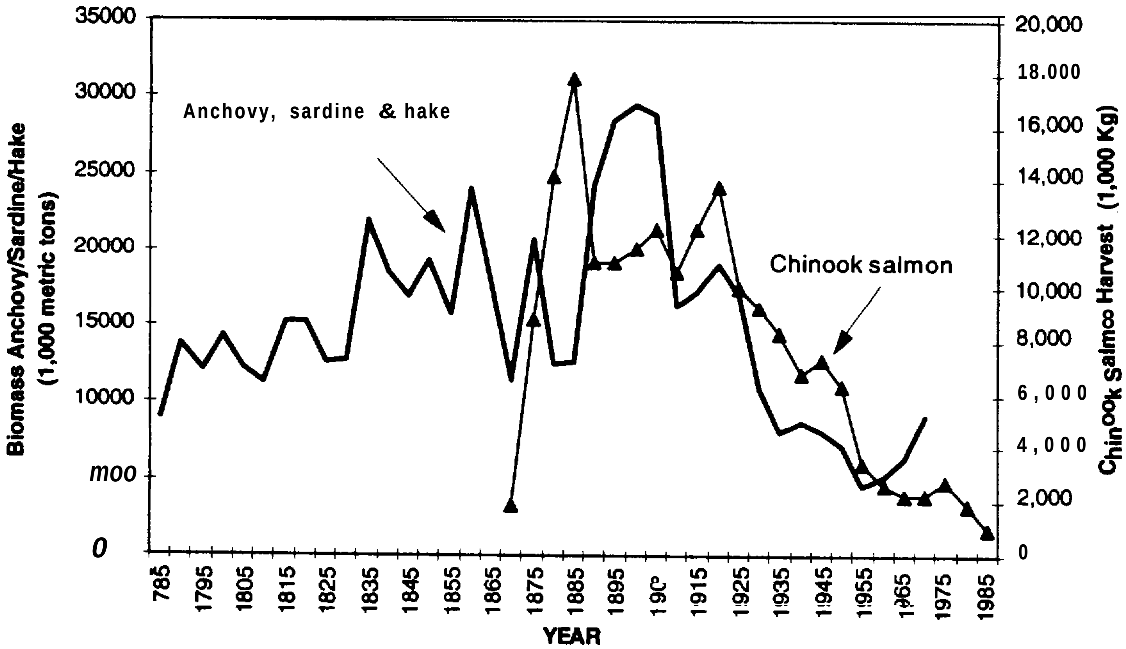

Figure 5. **Total biomass of anchovy, sardine and hake in the California Current in thousands of metric tons. Standing stock inferred from contemporary stock size and scale deposition rates in 18th and 19th Centuries. Commercial catch of Columbia chinook salmon in millions of fish. Annual chinook salmon harvest averaged by 5 years intervals.** *(Source: Smith 1978; Beiningen 1976; ODFW and WDF 1995)*

(Figure 5) suggesting that oceanic conditions were exerting a strong influence on the pattern of abundance.

The pattern of abundance of chinook salmon in the Columbia River was also consistent with an index of natural changes in the quality of freshwater habitat, inferred from spacing of growth rings on trees (Figure 6). A period of cool-wet weather especially in the Snake Basin around 1900 was followed by a severe hot-dry period which lasted through the end of the data record in the mid- 1940s. A study using a larger sample of trees over a greater area in the Columbia Basin also showed a higher level of precipitation around 1900 followed by dryer conditions through the 192Os, 1930s and 1940s (Graumlich 1981).

The decline in chinook salmon in the 1920s and 1930s (Figure 3) was in part a response to natural changes in both freshwater and marine environments. Other salmon species in the Pacific Northwest showed similar patterns of decline in the same period. Commercial landings of coho ***(Oncorhynchus kisutch),*** sockeye ***(Oncorhynchusnerka)*** and chum ***(Oncorhynchus keta)*** salmon in the Columbia River, chinook and coho salmon in Oregon coastal streams were also in decline between 1920B 1940 (Lichatowich in press). The catch of wild chinook and coho salmon in Puget Sound showed significant declines between 1896B1934 (Bledsoe et al. 1989).

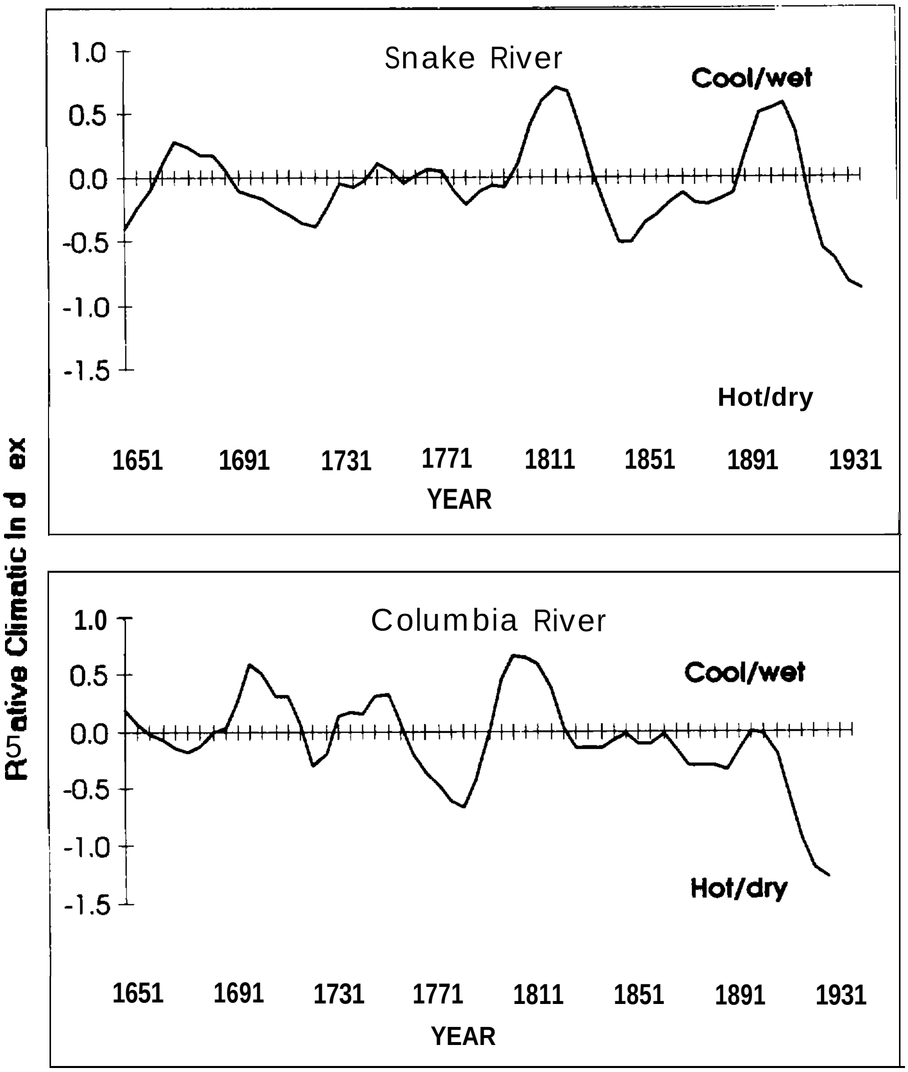

Figure 6. **Fluctuation in an index of climate inferred from growth rings of trees in the Columbia Basin. Shown are five year moving averages of relative departures from a 280 year mean. Positive departures indicate cool/wet climate and negative departures indicate hot/dry climate. (Source:** *Fritts 1965)*

Conventional wisdom attributes the decline of Pacific salmon in the Columbia River and elsewhere in the Northwest to over harvest, habitat destruction and the side effects of artificial propagation. They were certainly major factors in the decline. However, superimposed on those human factors were natural changes in productivity. The interactions between natural fluctuations in productivity and human activities over the past 100 years probably increased the depth of the natural troughs and depressed the height of the natural peaks in salmon production.

Natural Fluctuations in Abundance – Management Implications

The situation just described has important implications for salmon management, and those implications, if not recognized, can be detrimental to the long-term recovery of salmon. The region is currently in what appears to be a climatic pattern that leads to low salmon productivity. This natural condition is aggravated by persistent overharvest, a century of habitat degradation and poor hatchery practices. The depleted status of many salmon populations throughout their range south of British Columbia has caused federal, state, tribal and private organizations to commit significant resources to salmon restoration. However, if managers are not fully aware of the status of the natural cycle in salmon productivity, an increase in production due to a natural change in productivity might be interpreted as a positive outcome of restoration efforts. That mistake could lead to premature reduction in restoration efforts and reduced vigilance in habitat protection. The result would become evident during the next cycle of low productivity and be expressed as an even lower trough in productivity (Lawson 1993).

Two examples are used to illustrate the possibility of misinterpretation: The rapid increase in coho salmon production in the Oregon Production Index (OPI) in the early 1960s and the search for factors causing the decline of salmon in the early decades of this century.

Coho Salmon in the OPI

The OPI is an index of abundance which has been used to manage the harvest of coho salmon since the 1960s. It is the combined number of adult coho salmon that can be accounted for in the general area south of Ilwaco, Washington (ODFW 1982). The pattern of coho salmon harvest in the OPI is also an index of the long-term, natural fluctuation in climate patterns and its resulting influence on ocean productivity and coho salmon production (Figure 7).

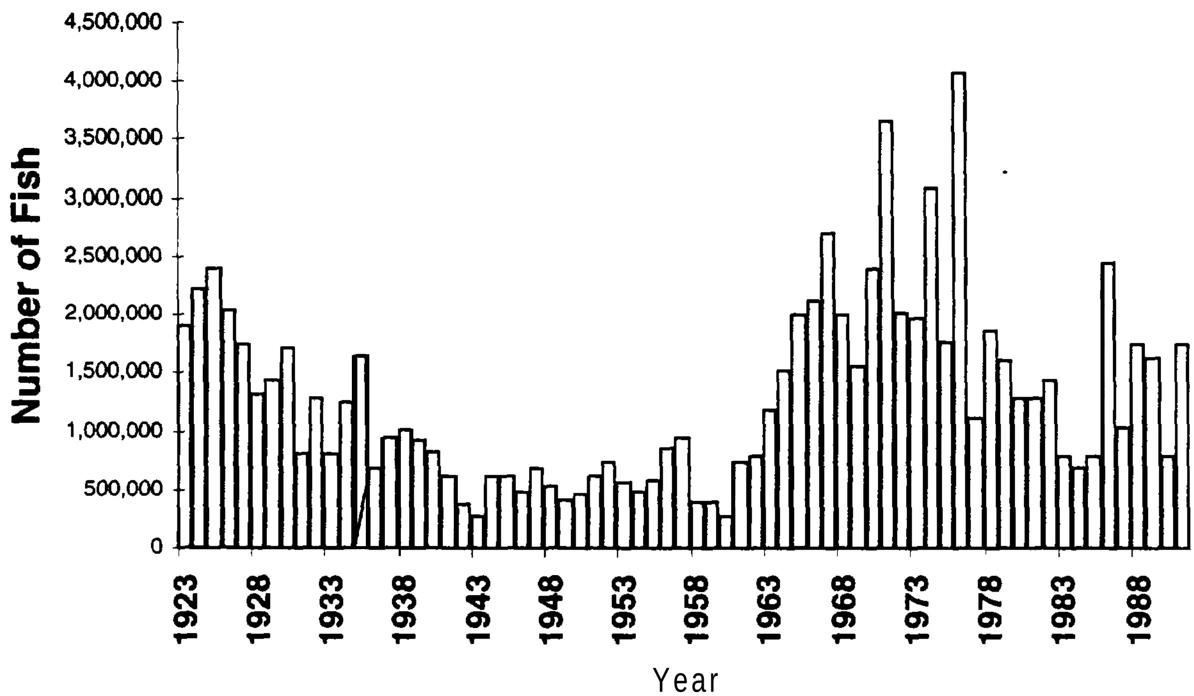

Figure 7. Total ocean harvest of coho salmon in the Oregon Production Index (OPI). (Sources: 1923-1970 from unpublished data Oregon Department of Fish and Wildlife; 1970-1991 Pacific Fisheries Management Commission (1992)).

By 1923, the fishery for coho salmon was already in decline, however it is only from that date that reliable catch data are available. In 1921, the state of Oregon assessed a tax on all salmon landed in Oregon and two years later the state required a report on salmon landings along with the tax assessment. Following these requirements the quality of the harvest data improved (Mullen 1981). From 1923, the harvest of coho salmon in the OPI declined until the 1940s and remained depressed until the early 1960s when it increased dramatically. After 1977, the harvest went into another decline and has remained in a depleted condition (Figure 7). During the 193Os, salmon management institutions began recognizing the need to develop a scientific basis for their programs (Lichatowich et al. 1996). Much of the new emphasis on science was directed at improving hatchery operations. By the early 196Os, research on the prevention and treatment of diseases and the development of more nutritious feeds appeared to be yielding positive results – artificially propagated coho salmon showed increases in survival and began returning to hatcheries in increasing numbers. Harvest also increased (Figure 7).

Salmon managers generally attributed the increased production to the improved hatchery technology (Lichatowich and McIntyre 1987). Because they believed that the burgeoning fishery was the result of improved artificial propagation, salmon mangers allowed the fishery to grow to reduce the increasing surpluses of coho returning to hatcheries. Between 1960 and 1968, commercial fishing licenses in Oregon increased form 2,565 to 8,566 (Lichatowich and McIntrye 1987). As a consequence of the rapid expansion of the fishery and harvest rates geared to escapement needs of hatcheries, the wild stocks were overharvested and have showed no evidence of recovery (Figure 8). Escapements of coho salmon into natural production areas dropped from a high of 50 fish per mile in the 1960s to a low of 8 fish per mile in the 1980s (Cooney and Jacobs 1995). Over exploitation and degradation of habitat threaten the coastal stocks of coho salmon with extinction (Weitkamp et al. 1995) and the National Marine Fisheries Service has recommended giving them threatened status under the federal Endangered Species Act.

The decline of naturally produced coho salmon in Oregon coastal streams after 1976 has been attributed to a less favorable environment causing reduced ocean survival of salmon (Lawson 1993; Nickelson 1986). The change in ocean conditions was aggravated by excessive harvest and habitat degradation (Weitkamp et al. 1995) causing further reduction in current production of coho salmon (Lawson 1993). However, the depth of the current trough in production is in part an outcome of the misinterpretation of the increase in production in the early 1960s. In other words the current crisis in coho salmon management is the consequence of decisions made 30 years earlier. By attributing the increase in production in the early 1960s to improved hatchery technology, managers believed they had achieved a permanent solution to the depressed coho fishery in the previous three decades. Management emphasis shifted to the hatchery program and wild stocks were overharvested which in combination with continued habitat degradation, pushed the coho salmon to the point where extinction is now a legitimate concern. Lawson (1993) put forth one explanation of how the misinterpretation of changes in salmon production due to climate change can be detrimental to the long-term persistence of the populations.

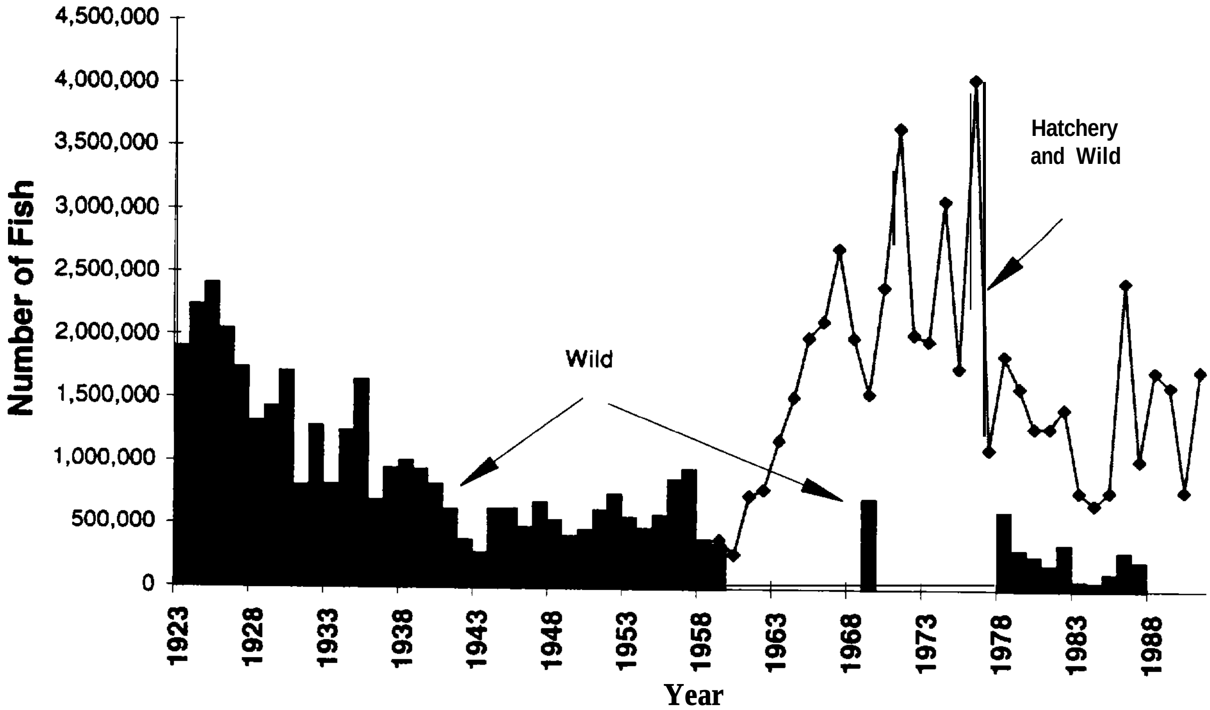

Figure 8. Total ocean harvest of coho salmon in the Oregon Production Index partitioned into wild and hatchery fish. Solid bars are catch of wild coho salmon. All coho salmon are assumed to be wild before 1960. (Source: 1969 *wild harvest ODFW (1982); 1979-1987 wild harvest, L. Borgerson, ODFW 12192)*

The Decline in Coastal Fisheries

In the previous example, an increase in salmon production was erroneously attributed to improved hatchery technology. In this example, the causes for the decline in salmon production during the 193Os, 1940s and 1950s was misinterpretated. As discussed above the decline in salmon abundance in the first half of this century coincided with changes in ocean productivity and in climate patterns affecting freshwater habitats (Figure 5). The pattern of declining abundance was apparently determined by the changing climate, however, the depth of the trough was probably increased by other factors such as habitat degradation and excessive harvests.

The causes for the decline of salmon in Oregon's rivers was investigated by McKernan et al. (1950). They attributed the decline in production to three factors: logging, changes in streamflow (low summer flows and floods), and fishing intensity. McKernan et al. (1950) did recognize that the widespread nature of the decline indicated a causative factor that was exerting a similar effect on all streams. They considered changes in ocean conditions but the data they had access to was inadequate and they failed to demonstrate a relationship between ocean conditions and salmon production. The factors they identified were probably contributors to the depth of the production trough in the 1930s to 195Os, but the overall pattern of decline was set by changing climate conditions in both freshwater and ocean.

Long-term (40 to 60 years) fluctuations in climate that establish the patterns of production in Pacific salmon means that the results of management activities have to be evaluated over extended periods (Lawson 1993). Based on past recorded experience with large scale changes in salmon production, evaluations carried out over several decades would be more consistent with the observed 40 to 60 year cycle rather than a time scale geared toward a single generation of the target salmon species (2 to 5 years).

HABITAT DEGRADATION

In the 150 years since the first major influx of settlers followed the Oregon Trail into the Pacific Northwest, the Columbia River has been subjected to intensive development and use of its water resources. Development in the Columbia Basin east of the Cascade Mountains has a long history of cumulative degradation of watersheds and salmon habitat (e.g. Lichatowich & Mobrand 1995; McIntosh et al., 1994; Wissmar et al. 1994). Irrigation was one of the first forms of water development and it was initiated almost as soon as the region was colonized by Euroamericans. About 900 irrigation withdrawals in Oregon, Washington and Idaho — many of them unscreened or poorly screened — kill juvenile salmon directly or create lethal conditions for salmon by reducing flows and promoting an increase in temperature in the tributary streams.

There are fifty eight dams that span the Columbia River or its major tributaries which are operated primarily for hydropower production and another 78 dams are multiple purpose including hydropower production (NPPC 1986). Poor grazing and logging practices and residential development have also contributed to the degradation of Pacific salmon habitat.

Detailed reviews of habitat change in the Columbia Basin can be found in McIntosh et al. (1994), Wissmar et al. (1994) and Rhodes et al. (1994).

Irrigated agriculture was a major source of habitat degradation in the late 19th Century. Irrigation impacted anadromous salmonids in four ways: 1) migrating juveniles were diverted into unscreened irrigation ditches; 2) tributaries were dewatered eliminating habitat and blocking migration of juvenile and adult salmon; 3) dams that diverted water into irrigation ditches blocked migration of adults; and 4) the withdrawal of water contributed to lethal temperatures in the lower mainstems of tributary streams. As early as 1890, fishery managers viewed the loss of juvenile salmon in irrigation ditches as a serious problem and they requested legislation to prevent the losses (Oregon State Board of Fish Commissioners (OSBFC) 1890). The problem persisted and was repeatedly described by managers in Oregon (ODF 1901; OSBFC 1892; OSFGP 1896) and Washington (Washington State Department of Fish and Game (WSDFG) 1904). All the streams in the steppe and shrub-steppe zone are subject to irrigation diversion.

Most of this discussion will focus on the Yakima River in eastern Washington State because it has an accessible record on irrigation development and its effects on Pacific salmon. The Yakima River enters the Columbia at RK 539 (Figure 1). The first irrigation ditch in the Yakima Basin was constructed in 1853, and the first ditch of large size was finished in 1875 (Kuhler 1940). Between 1905 and 1930, the amount of land under irrigation increased from 12 1,000 to 203,000 acres (Robinson 1957) and by 1947 it had reached 354,877 acres (Davidson 1965). Efforts to protect salmon from unscreened irrigation ditches did not begin until 1930 (Davidson 1965).

Prior to 1930, the withdrawal of water from rivers into unscreened irrigation ditches killed significant numbers of juvenile salmon, however, we have found only one attempt to quantify those losses before 1930. In 1920 Dennis Winn, the field superintendent for hatchery work on the Pacific coast for the U. S. Bureau of Fisheries, was directed to investigate the effects of irrigation on salmon and steelhead in the Yakima River. Although Mr. Winn made his inspection trip during the winter, after the ditches had been shut down, and few juvenile salmon were migrating, he still found evidence of significant numbers of salmon in the ditches ***(Pacific Fishermen 1920).*** In his report, Winn discussed a study conducted in 1916 of the loss of juvenile salmon due to irrigation in the Yakima River. Two hundred acres of irrigated land were monitored and all the juvenile salmon that were diverted onto those fields and killed were counted. The study concluded that 20 fish/acre or a total of 4,000 fish in the 200 acres were killed. Migrating salmon made up 90 percent of the dead fish. When the subsample was extrapolated to all irrigated land, an estimated 4,500,000 migrating salmon were lost with each watering ***(Pacific Fisherman*** 1920). The estimate of total losses needs to be viewed with caution, however, it does indicate a problem of significant proportions.

In the Yakima River, the progeny of spring and summer chinook salmon were highly vulnerable to unscreened diversions because their spawning areas were in the middle and upper reaches of the river above the irrigation diversions. The juvenile spring and summer chinook progeny had to migrate past and often into the unscreened ditches (Figures 9, 10 and 11).

Irrigation development in other basins in the steppe and shrub-steppe zone was similar to the development in the Yakima. Dams and diversions in the lower Umatilla River extirpated the native chinook and coho salmon early in this century. In the Umatilla River, water appropriated for irrigation exceeds the natural stream flow – 4,000 water rights totaling 130 m^3/sec have been granted, but flows during the summer irrigation season in June, July and August are 3.4,0.6 and 0.65 m^3/sec. Water diversions in the Umatilla River frequently dewater the lower mainstem (CTUIR & ODFW 1990). By 1914, water rights in the Deschutes River above the city of Bend, Oregon exceeded stream flow by 40 times (Nehlsen 1993). Irrigation contributes to severe habitat degradation in the John Day and Tucannon rivers (Lichatowich & Mobrand 1995; WDF et al. **1990).**

Grazing and Timber Harvest

Grazing and timber harvest ranked one and two in terms of their impact on riparian areas in 11 river basins in eastern Oregon (Wissmar et al. 1994). Livestock grazing intensified in the latter decades of the 19th century. The number of sheep in the Yakima Basin grew from 5,000 in 1879 to 16,000 in 1889 and reached 261,000 in 1899. The same general trend occurred in Oregon. Sheep were introduced to eastern Oregon in 1880 and by 1900 the small town of Shaniko in the high desert between the John Day and Deschutes rivers was a major worldwide shipping center for wool. The explosive growth in livestock on the open range came at a time of favorable climate at the turn of the century which was generally cooler and wetter than average. Climate changed after 1920 to hotter and dryer conditions and overgrazing became so apparent that congress passed the Taylor Grazing Act of 1934.

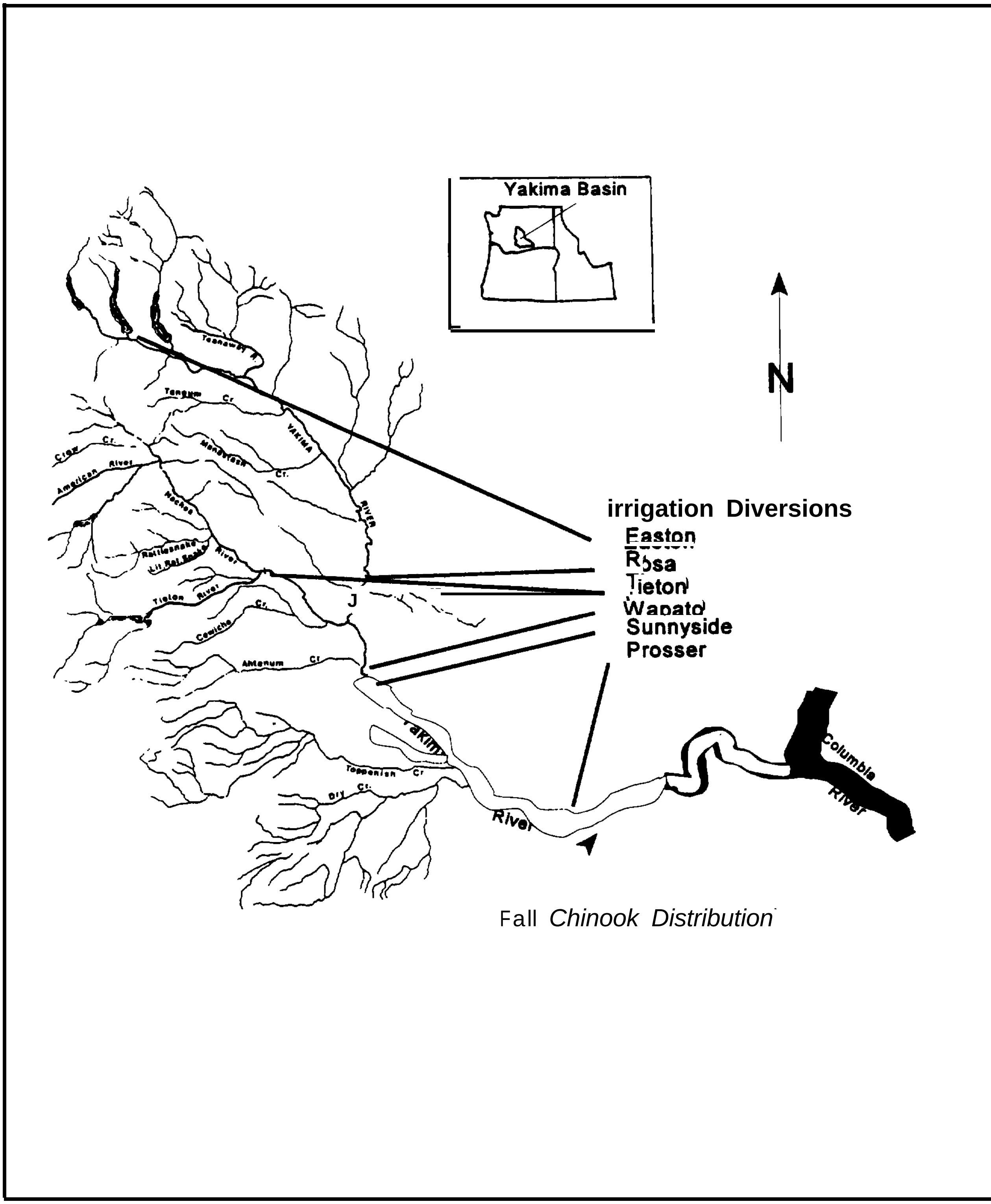

Figure 9. Location of major irrigation diversions and the current spawning distribution of fall chinook salmon in the Yakima Basin. (Source: *personal communicution, Bruce Watson, CTYIN, August* ***31, 1994*****)**

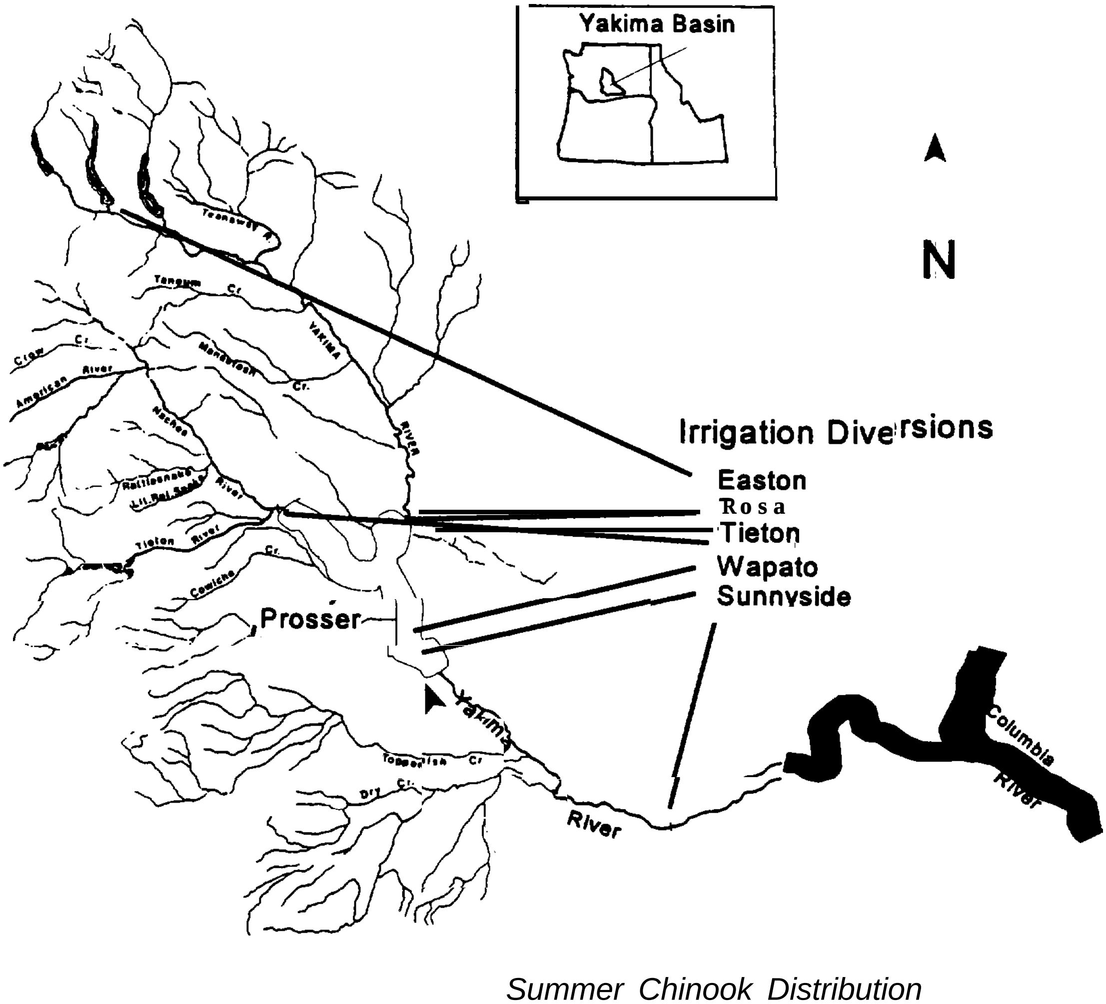

Figure 10. **Location of major irrigation diversions and the historic spawning distribution of summer chinook salmon in the Yakima Basin. (From CTYIN et al 1990)**

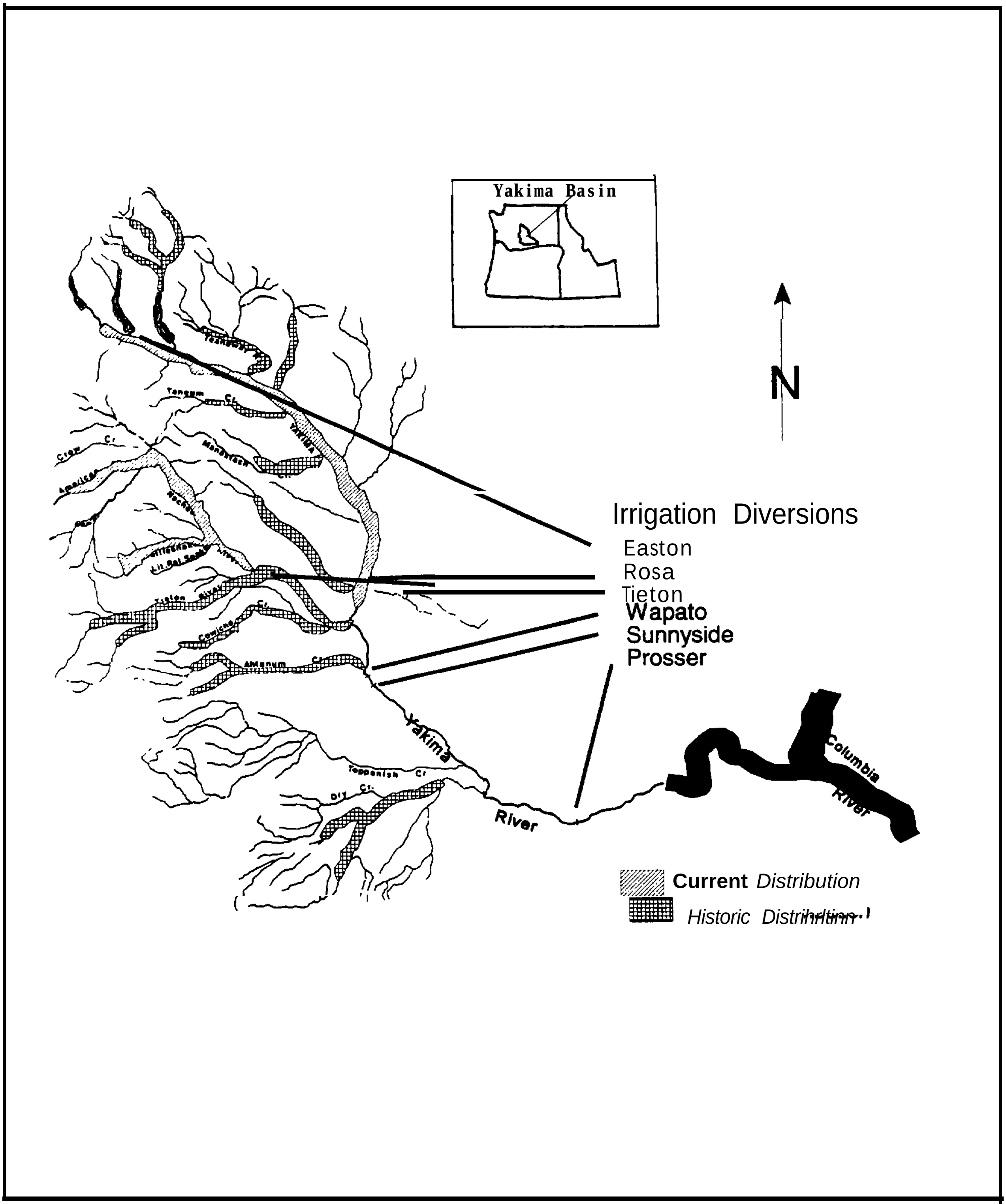

Figure 11. **Location of major irrigation diversions and the current and historic spawning distribution of spring chinook salmon in the Yakima Basin. (Distributions are** *estimates obtained from CTYIN et al. 1990; Personal communication, Bruce Watson, CTYIN, August 31, Z994.)*

High densities of grazing livestock destroyed riparian areas (Wissmar et al. 1994). However, homesteaders also destroyed riparian areas to develop better pasture. Oliver (1967 p 7-9) described the land clearing on his father's ranch in the John Day Basin in the 1880s.

> ***'...One of the first jobs on the Clark homestead was to clear off the brush and trees. Big Cottonwoods grew all along the river and the meadows were covered by wild thorn bushes, to be chopped out by hand.***
>
> ***'...Father took out the big bends, straightened the channel, rip rapped the banks and made each meadow safe. He dried up the wet places. For draining, he dug by hand ditches about two feet deep and 18 inches wide. "***

Overgrazing and land clearing in the high desert eliminated riparian zones and caused streams to downcut in the latter decades of the 19th and early 20th centuries. For example, a review of diaries and land surveys established that Camp Creek, a tributary of the Deschutes River downcut, lost its riparian cover and the surrounding valley underwent desertification between 1885 and 1903. The degradation of Camp Creek was attributed to the effects of variable climate and intensive grazing (Buckley 1992). In addition land was compacted by the large numbers of sheep and cattle altering the rate of water run off.

Timber harvest in the watersheds east of the Cascade Mountains intensified later than in the coastal forests. Logging increased dramatically in the 1930s and 1940s in Oregon and has continued to increase but at a slower rate. Timber harvest in eastern Washington has been about one third the Oregon harvest (Wissmar et al. 1994). Logging practices, especially prior to the 197Os, degraded riparian zones, introduced fine sediments to spawning gravels, altered flow patterns and reduced structural complexity of the streams.

The loss of riparian areas through grazing and timber harvest and reduced flows because of irrigation withdrawals combined to create lethal conditions in the lower reaches of the streams in the steppe and shrub-steppe ecological zone (Table 1). The total habitat loss and degradation in the early decades of this century was extensive, and at least 50 percent of the most productive spawning and rearing areas were lost by the 1930s (OFC 1933).

Many of the most egregious land and water development practices that degraded salmon habitat in the subbasins were gradually stopped or improved after 1940. Grazing pressure declined after the climate shifted in the early decades of this century. Gold mining declined and forest management came under better regulations designed to protect stream corridors especially after the 1970s. Irrigation diversions are slowly being screened. Some streams east of the Cascade Mountains have showed continued deterioration in habitat quality while others have improved over the past 50 years (e.g., McIntosh et al. 1994; Smith 1993). However, the development of the region since 1850 left behind a legacy of degraded habitat that time and increasing concern for salmon have not overcome. Recent improvement in habitat does not mean those streams have recovered from past degradation, it only means they have improved from baseline conditions described in the 1930s. However, by the 1930s the stream habitats had already experienced 80 years of development and degradation.

Table 1. Habitat suitability for juvenile chinook salmon in the lower reaches of the study subbasins.

Subbasin	Comments on Habitat	Source
Yakima	Lower river below Prosser (RM 47.1) frequently exceeds 75°F and occasionally reaches 80°F in July and August rendering the lower river uninhabitable by salmonids.	CTYIN et al. 1990
Tucannon	Water temperatures in lower river at or above lethal levels.	WDF et al. 1990
Umatilla	Lower 32 miles subject to irrigation depleted flows and temperatures exceeding upper lethal limits for salmonids.	CTUIR and ODFW 1990
John Day	Juvenile chinook salmon generally not found in the river where temperatures reach 68°F. High stream temperature eliminates juvenile rearing habitat in the lower river.	Lindsay et al. 1981, ODFW et al. 1990
Deschutes	In the mainstem Deschutes River, summer temperatures are adequate for chinook salmon. However, there are temperature problems in the lower reaches of the tributaries where spring chinook salmon spawn. In addition Ceratomyxa *shasta* limit the survival of juvenile chinook salmon in the mainstem through the summer months.	Ratliff 1981, ODFW and CTWSR 1990

Mainstem Dams

Mainstem dams in the Columbia Basin block or constrain the migration of salmon, kill juveniles and adult fish and eliminate spawning and rearing habitat. In addition, the large storage reservoirs in the headwaters do not directly affect salmon migration but those dams are used to manipulate flow for the benefit of power production, recreation and flood control. The result is a significant change in the historical flow patterns in the tributaries and in the mainstem Columbia River. The summer freshet has been drastically reduced in order to accommodate other uses (Figure 12).

The mainstem dams and their operation are direct impediments to migration and sources of juvenile and adult mortality. The reservoirs behind the dams alter the rearing habitat of juvenile salmon and the migratory habitat of juveniles and adults. Ecological changes in the river due to the dams and reservoirs and the introduction of exotic species have increased predation on/or competition with juvenile salmon. Mainstem dams and reservoirs slow the migration of juvenile chinook salmon (Park 1969; Raymond 1969) and have led to a critical hypothesis in the current fish and wildlife program that survival is related to the rate of migration, and that migration rate is a function of flow (NPPC 1994).

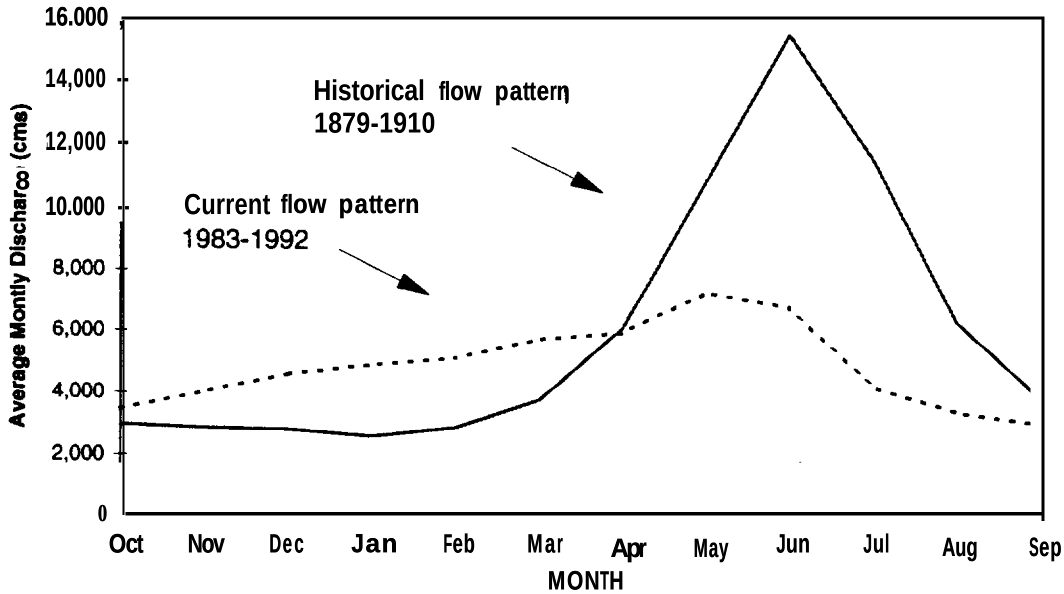

Figure 12. Change in monthly average flows for the periods 1879 to 1910 and 1983 to 1992 in the Columbia River at The Dalles, Oregon. (Source: *Hydrosphere, Inc. 1990)*

CHANGES IN LIFE HISTORY PATTERNS OF CHINOOK SALMON

Chinook Salmon Life Histories

Healey (199 1) structured the life histories of chinook salmon around two patterns of freshwater residence during the juvenile life stage. The two patterns were first described by Gilbert (19 12) who labeled them ocean and stream types. Ocean type fish exhibit a short freshwater residence, usually migrating to sea within six months of emergence. Stream type fish migrate to sea in the spring of their second year. In some northern stocks, juvenile chinook may remain in freshwater for two or more years. In general, stream type life histories are found in rivers north of 56°N and in populations that spawn in the upper reaches of rivers that penetrate long distances inland such as the Fraser and Columbia rivers. Between 56°N and the Columbia River both life history patterns are present. South of the Columbia River the ocean type life history dominates (Healey 1991; Taylor 1991). Healey (1991) associated the stream type life history variant with adult spawning migrations in the spring and summer and the ocean type variant with adult spawning runs in summer and winter. This generalization breaks down, however, on the California, Oregon and Washington coasts where the spring chinook runs are often comprised of a significant proportion of fish with ocean type life histories. For example, in the Rogue River, 95 percent of the adult spring chinook exhibit the ocean type life history pattern (Nicholas and Hankin 1989).

Life Histories in the Mainstem Columbia

Juvenile chinook salmon were collected by beach seine in the lower Columbia River in 1914, 1915 and 1916 (Rich 1920). Interpreting seine catches in terms of migration is problematic, but those data are the only early information available on the presence and probable migration timing of juvenile chinook salmon in the mainstem Columbia. Those data suggest that the migration of ocean type juveniles in the mainstem Columbia River extended through the spring, summer and fall (Figure 13). The ocean type life history dominated the seine catches.

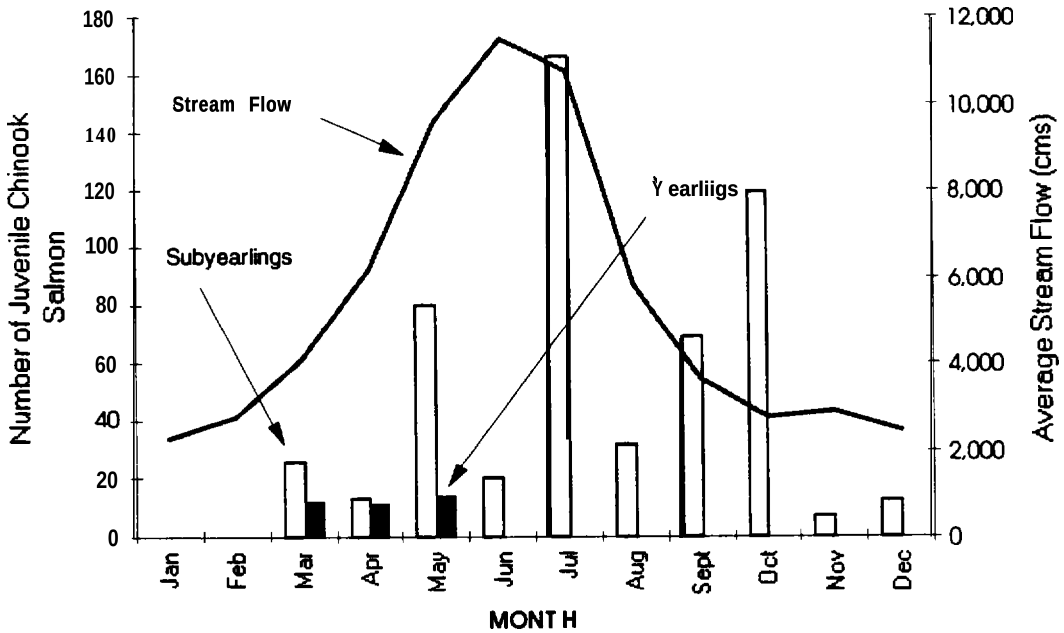

Figure 13. Average monthly catch of juvenile chinook salmon in the lower Columbia River 1914 to 1916. Average monthly stream flow at The Dalles, Oregon for 1916. (Source: *Rich 1920; and Hydrosphere, Inc. 1990)*

In 1919 the age distribution of returning adults and their juvenile life histories (ocean or stream type) were determined from an analysis of scales collected from adult chinook salmon in the lower Columbia River (Rich 1925). The percentage of the samples exhibiting stream and ocean type life histories changed through the migratory season. Stream type fish dominated during May, June and early July and ocean type dominated during late July, August and September (Table 2). These data led to the conclusion that juveniles of the spring run have the stream type life history and juveniles of the fall run have the ocean type life history pattern (Rich 1925). Unfortunately, the data in Table 2 were obtained in 19 19 or after the spring/summer chinook runs had already experienced significant declines in abundance. It should be noted that some spring chinook salmon did exhibit the ocean type life history pattern — as high as 38 percent in May.

Selective mortality on the ocean type life history in spring chinook salmon could explain the seasonal distribution of life history patterns in Table 2. Juvenile spring chinook migrating downstream in the summer (ocean type) were extremely vulnerable to the unscreened irrigation ditches and to elevated temperatures in the lower mainstems of the tributary streams. Fall chinook spawn below irrigation diversions in the subbasins or in the mainstem of the Columbia River and were not subjected as much to those sources of mortality.

Prior to extensive development, juvenile chinook salmon migrated throughout the year (Rich 1920) so identification of distinct ocean and stream type life histories from scale patterns was not easy (Rich & Holmes 1928). In fact, the majority of the chinook salmon scales analyzed showed

Table 2. **Percentage of ocean and stream type life histories of adult chinook salmon returning to the Columbia River in 1919. Sample size in parenthesis.** *(Data from Rich (1925))*

Month	Date and Sample Size		Percentage Ocean Type	Percentage Stream Type
May	10	(81)	2.4	97.6
	13	(233)	10.7	89.3
	16	(366)		100.0
	17-18	(108)	9.3	90.7
	27	(74)	38.7	61.3
	30-31	(149)	6.0	94.0
June	10	(32)	35.0	65.0
	16	(186)	9.1	90.9
	17	(240)	17.3	82.7
	24-25	(91)	63.0	37.1
July	3	(51)	88.3	11.8
	7	(167)	85.6	14.1
	16	(296)	77.6	22.4
	28	(96)	98.0	2.0
August	5	(36)	75.0	25.0
	6	(167)	92.6	7.4
	22	(182) (93)	92.6	7.4
September	12	(187)	87.4	12.7

neither a typical stream nor ocean type life history pattern, but an intermediate pattern indicating that the juveniles spent part of their first year in freshwater and part in saltwater (Rich & Holmes 1928). Because of this uncertainty, some late migrating, ocean type fish might have been classified asstream type. At the time of Rich=s study, conventional wisdom held that the spring run fish had the stream type life history, so any doubt in the interpretation of scale patterns of spring chinook was probably resolved in favor of the stream type life history.

The current timing of juvenile salmon migration through the mid-Columbia and lower Snake rivers is monitored at mainstem dams and reported annually (e.g., DeHart 1992). At Bonneville Dam (RK 233) the yearling (stream type) migration was 90 percent complete by May 25 and the subyearling (ocean type) migration was 90 percent complete by July 8 in 1990 (Figure 14). Migration is of shorter duration and occurs earlier than indicated by the historical data (Figure 13). In recent years, less than 1 percent of the adult spring chinook sampled at Bonneville Dam exhibited the ocean type life history (Fryer et al. 1992) where as in 1919 the ocean type like history was observed in 2-38 percent of the spring chinook sampled (Table 2).

Life Histories in the Subbasin

Observations of juvenile salmon in irrigation ditches in the Yakima River and anecdotal information from the Umatilla River suggest the presence of an ocean type life history pattern in spring chinook salmon in those two rivers. The Yakima River information comes from the work diaries of two employees of the Washington Department of Fisheries who observed the presence of salmon in irrigation ditches in 1928, 1929 and 1930. In 1928, the peak of the downstream migration was late July through early August and this appeared to be the normal timing (unpublished work diary of H. 0. Haggatt, May 26, 1928 to October 24, 1928). A July migration peak is consistent with the ocean type life history.

In 1929 and 1930, juvenile chinook salmon found in the irrigation ditches in the Yakima Basin were counted and their lengths recorded. The Wapato Ditch was sampled in 1929 from mid-June to mid-July and in 1930, mid-July to mid-September. The Wapato Ditch is located above the fall chinook spawning distribution so juvenile chinook observed there were from the spring or summer race (Figures 9, 10 and 11). In 1929, few fish were observed in the Wapato Ditch before sampling ended in early June, and in 1930, the number of juvenile chinook appeared to peak in late July with fewer fish in August and September (Figure 15). Movement of juvenile chinook salmon into the irrigation ditches indicates those fish were actively migrating downstream through the summer. The length of juvenile chinook salmon in 1930 was 8 cm or larger (unpublished work diary of E. Brannon, Sr., Washington Department of Fisheries, for 1929 and 1930).

The presence of fingerling chinook salmon, 8 cm in length, in July suggests high growth potential which is a necessary condition for the ocean type life history (Taylor 1990). Currently, yearling spring chinook salmon (stream type) begin migrating past Prosser (RM 47) in March, and by late April or early May, 75 percent of the migration is complete. The migration of juvenile fall chinook (ocean type) past Prosser is 50 percent complete by the end of May. Water temperature in the lower Yakima River are lethal for juvenile salmon by late July (Table 1).

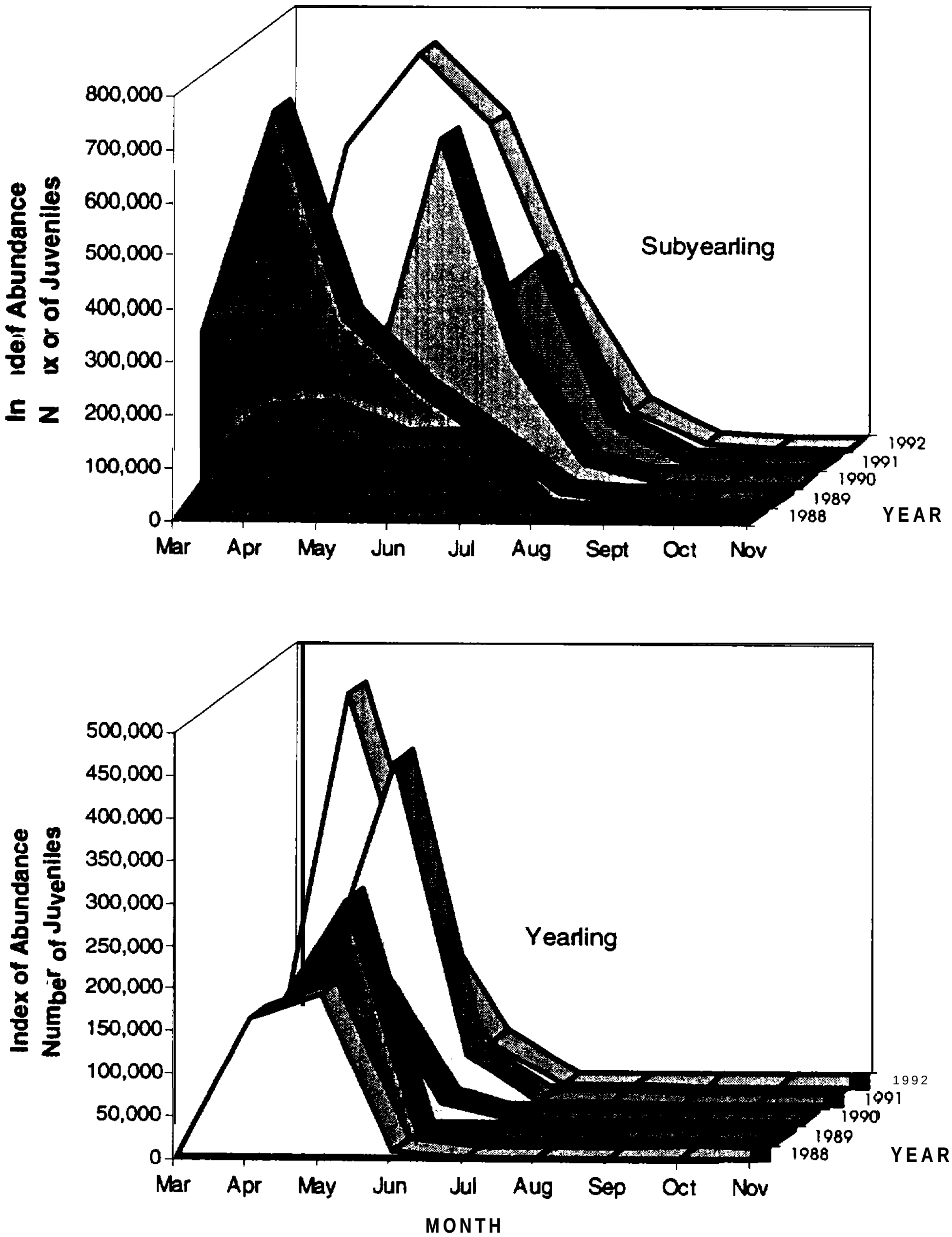

Figure 14. The index of abundance of subyearling and yearling chinook salmon migrating past Bonneville Dam, 1988 to 1992. *(Source: Fish Passage Center, Portland, Oregon).*

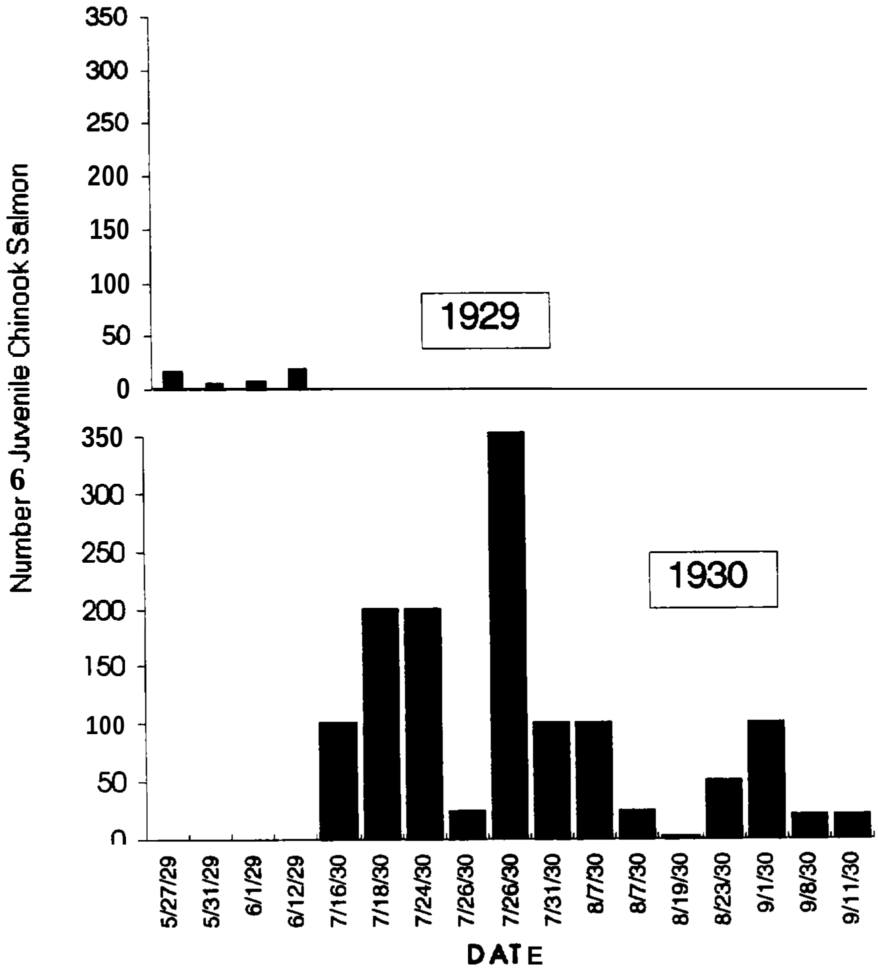

Figure 15. The number of juvenile chinook salmon observed in the Wapato Ditch (Yakima River) in 1929 and 1930. *(Source: Working diary* ***of*** *E. Brannon, Sr.)*

An anecdotal observation suggested a late summer migration of juvenile chinook salmon in the Umatilla River. In 1904 the ***Pacific*** Fisherman published a report on a new device to be placed in streams to limit the destruction of juvenile salmon in irrigation ditches. In the same article, the ***Pacific Fisherman*** (1904 p. 2 1) stated:

> ***"...Another fruitful source of trouble is the drying up of streams near their mouth in the summer, due to the exhausting irrigation further up and evaporation. This prevents large numbers of fish which head toward the Columbia River in September from ever getting to their destination. They come down as far as they can and are lost."***

Although the species was not identified, this observation is only consistent with the subyearling migrant pattern in chinook salmon. It should be noted this problem was identified in 1904.

For the Tucannon, John Day and Deschutes rivers, we could find no information on historical life history patterns. In all basins the current life history patterns are stream type for spring chinook and ocean type for fall chinook. An exception is the Deschutes River spring chinook population. About one percent of that population exhibits the ocean type life history.

The distribution of juvenile spring chinook in the John Day River suggests the possibility of ocean type life history if stream temperatures in the lower river were favorable. Juvenile salmon begin a movement downstream in June until they reach water temperature of 20°C. As the warmer water moves upstream through the summer, juvenile spring chinook retreat upstream to cooler refugia (Lindsay et al. 198 1). All spring chinook salmon show the stream type life history patterns in the John Day River.

DISCUSSION AND IMPLICATIONS

Development of a modem industrial economy in the Columbia Basin fragmented salmon habitat and eliminated or drastically altered much of the rearing areas used by juvenile chinook salmon. By 1930,50 percent of the best spawning and rearing areas had been destroyed or degraded (OFC 1933). For Pacific salmon, because migration is a central feature of the juvenile and adult life history, the connectivity among habitats – tributaries, subbasin, mainstem, estuary – is a critical component of ecosystem health (Lichatowich et al. 1995). Viewed from this perspective, salmon habitats become a series of geographically and seasonally important places where salmon carry out their life histories (Thompson 1959). The presence of those places (structural habitat features) is important but so is the ability to freely move between them at the appropriate times.

The ability to rear in the mainstems downstream from spawning areas is an important part of the life history of juvenile chinook salmon. Even juveniles that overwinter in freshwater often leave the tributaries and move into the mainstem to rear in larger pools through the winter (Healey 1991). In the Columbia Basin, this pattern has been observed in the Yakima River (CTYIN et al. 1990), Grande Ronde River (Burck 1993), Deschutes River (Lindsay et al. 1989), and Lemhi River (Keifer et al. 1993). Channel morphology and hydraulics suggest that habitat in the lower reaches of streams are more stable than in the smaller streams in the upper reaches of watersheds (Baxter 1961; Naiman et al. 1992). The continuous downstream movement of juvenile chinook salmon is a migration towards the historical center of habitat stability in the lower reaches of larger tributaries and the mainstem. Today those areas have lethal temperatures in the subbasins, and in the mainstem a dramatically altered ecology and far less hospitable environment for rearing juvenile salmon. The isolation of juvenile spring chinook to headwater refugia during the summer months eliminates the possibility of the population expressing the ocean type life history.

The lower reaches of streams flowing through the steppe and shrub-steppe vegetation zone are lethal to juvenile salmon (Table 1). largely due to irrigation withdrawals, grazing and timber harvest. The former reduces flow and influences temperatures. The latter destroys riparian cover and degrades structural habitat quality. Loss of shading from a healthy riparian zone also elevates stream temperatures. Lethal conditions in the lower mainstems of the subbasins isolates juveniles to refugia in upper reaches of a basin.

Although the downstream movement of juvenile chinook salmon may have appeared to be continuous, it can be partitioned into three overlapping migrations: The first in early spring consisting of fry and yearling smolts (ocean and stream types), the second in mid-summer consisting of subyearling migrants (ocean type) destined to enter the sea that year, and a third downstream movement of subyearlings in the fall where they overwinter until the following spring (stream type). As habitats are fragmented the ocean type life history is reduced or eliminated (Figures 16–17).

The evidence presented here supports a working hypothesis that the decline in abundance of chinook salmon was in part due to the loss of intrapopulation life history diversity following habitat fragmentation in the subbasins. Although the evidence supports the hypothesis, we recognize there is uncertainty that remains to be resolved. This paper does give support to broadening the approach to restoration of Pacific salmon in the Columbia Basin. There is a need for restoration planning that employs a greater use of historical reconstruction and a more inclusive analysis of the salmon's life history. As W. F. Thompson (1959 p. 208) pointed out, in our management of Pacific salmon we attach, "far greater importance to that which we see than to that which we do not." One way fishery managers "see" is through the conceptual frameworks and hypotheses that underlie restoration activities. When managers simplify the system in order to model it, and in the process ignore environmental history, habitat connectivity, and life history diversity, their vision is restricted and problem definition is inadequate. Oversimplification has led to a strong reliance on artificial propagation and emphasis on mainstem passage problems. Both of those are important elements of a restoration plan for the Columbia River. However, hatchery programs that have been implemented in ways that threaten biodiversity and solutions to passage problems have ignored the diversity of migration patterns in juvenile Pacific salmon. Finally irrigation, timber harvest and grazing which have contributed to fragmented habitat and reduced life history diversity of salmon, need to be integrated with needs of other resource uses. If preservation of salmon is important, then a broader understanding of salmon life history requirements must be integrated into all fishery management, restoration and enhancement approaches, and brought to the awareness of the public that sets the environmental agenda.

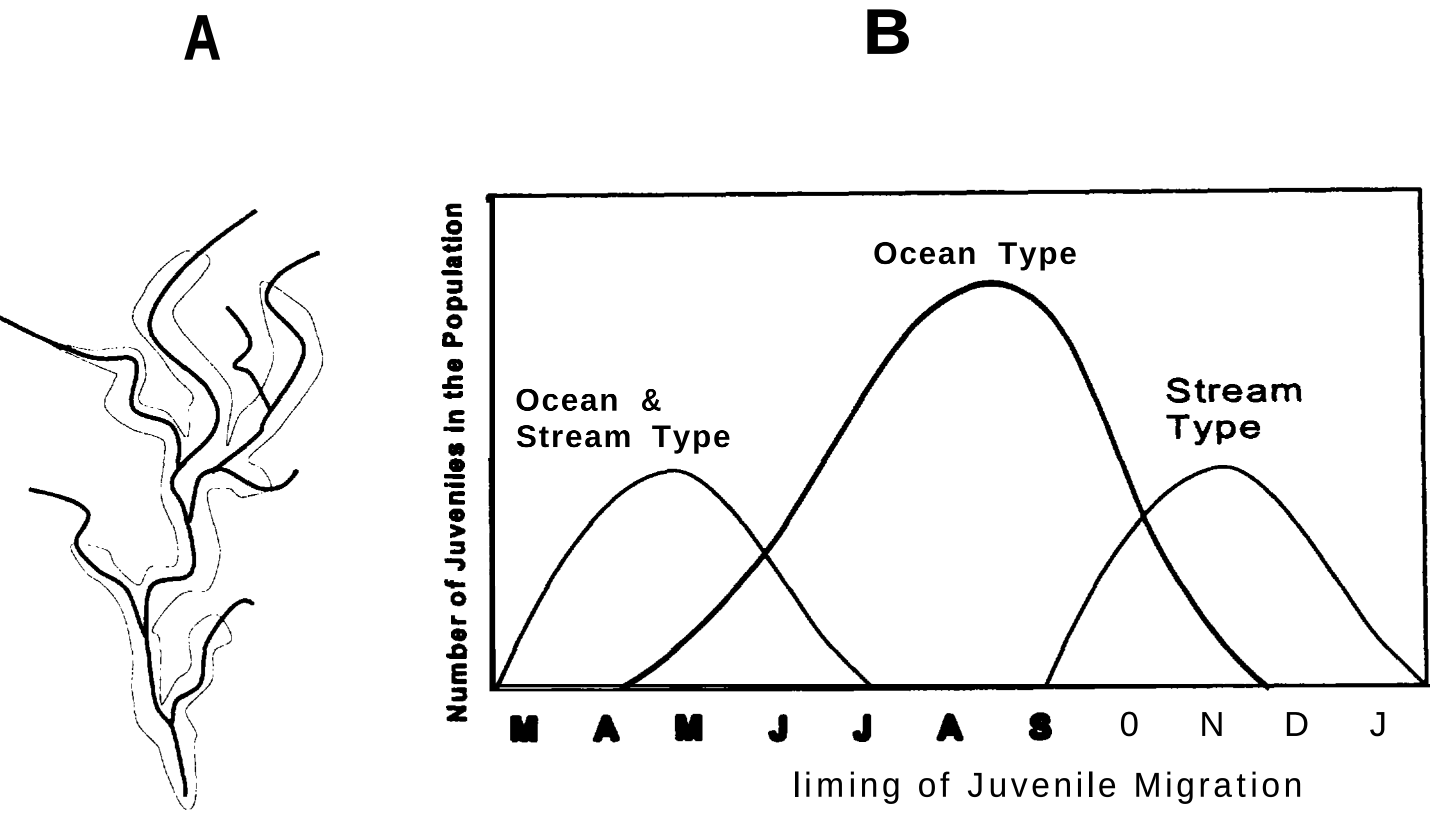

Figure 16. **Hypothetical portrayal of highly connected habitats (shaded area in A) in a watershed and the distribution of migration patterns of juvenile chinook salmon in the same basin (B).**

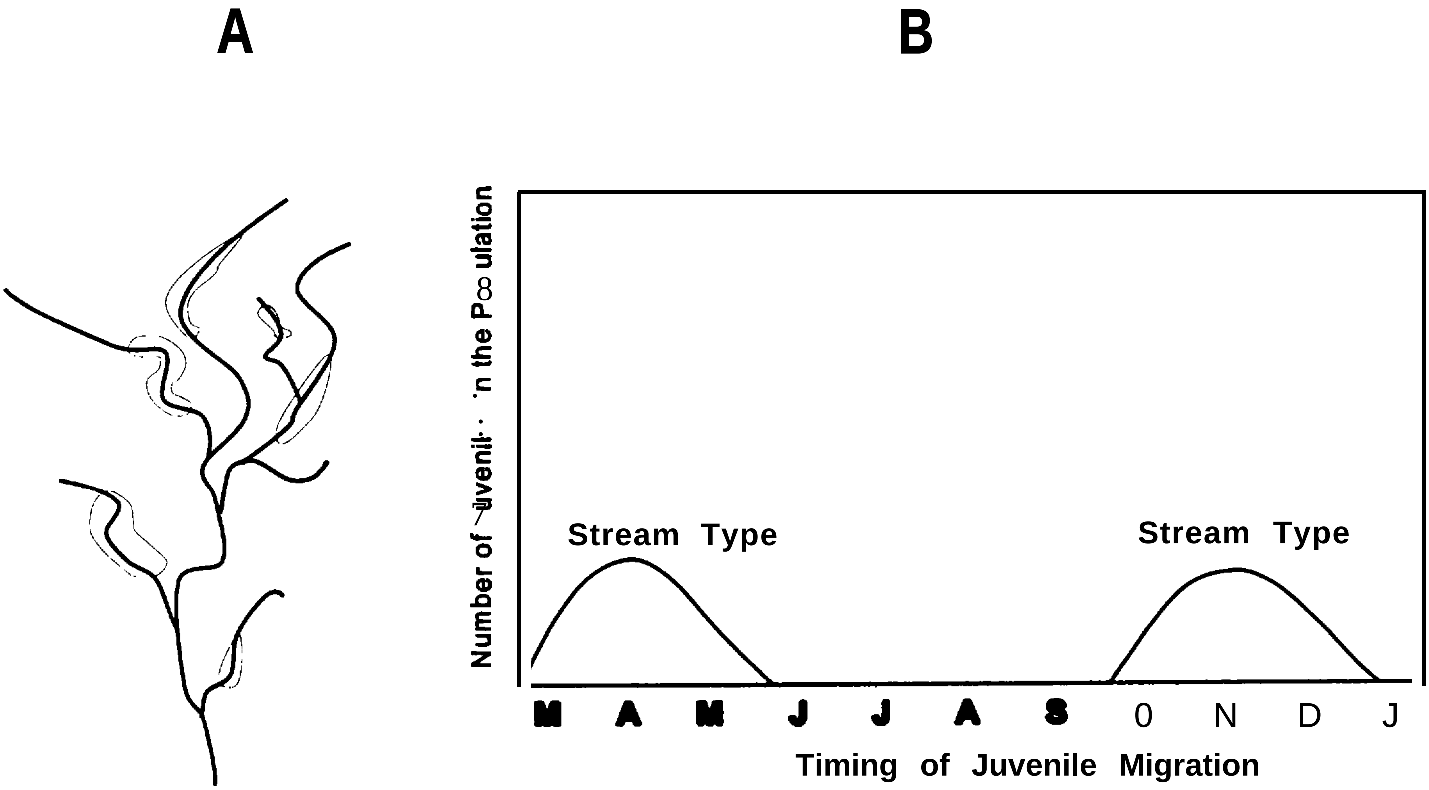

Figure 17. Hypothetical portrayal of fragmented habitats (shaded area A) disconnected from the lower reaches of tributaries and the mainstem by lethal conditions and the resulting migration patterns of juvenile chinook salmon in the same basin (B).

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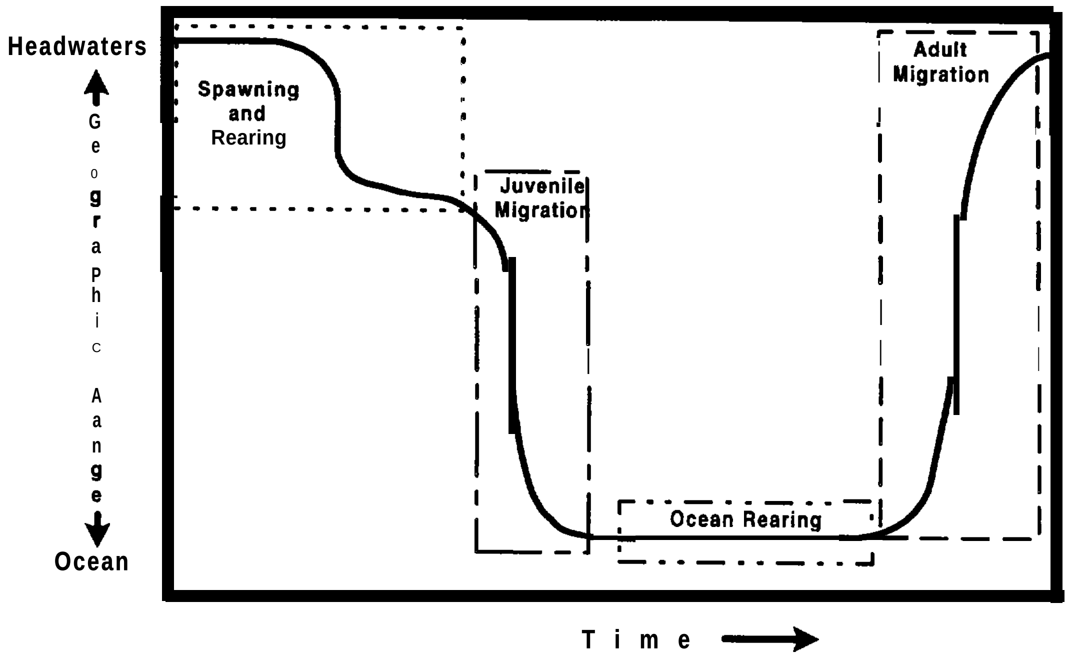

An Approach to Describing Ecosystem Performance "Through the Eyes of Salmon"

May 1996

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INTRODUCTION

Efforts to restore salmon populations usually begin with a search for the limiting factor -- the bottleneck that most restricts abundance. This perception of salmon population dynamics assumes that population density is the principal determinant of population performance. The bottleneck metaphor is appropriate when the quantity of food and space limit capacity for one or more life stages and when population abundance approaches this capacity.

There are at least three reasons why this narrow way of thinking about salmon performance needs to be expanded. First, there is ample evidence of reduced quality of habitat (Lichatowich and Mobrand 1995) affecting survival at all population densities. Secondly, we value not only abundance but also diversity of salmon populations (NPPC 1994); and thirdly, the search for *the* most limiting factor puts all other potentially beneficial measures on hold, assuming they will be ineffective unless the bottleneck is removed.

The topic of this paper is salmon ***performance*** - the characteristics of salmon populations that allow them to persist and abound. The bottleneck model sees performance as capacity; we contend that a useful measure of salmon performance must at least also include productivity (i.e. density independent survival) and diversity.

The purpose of this paper is to propose a measure of salmon performance which incorporates quantity, quality and diversity of population aggregates. We outline a habitat and life history based method of defining and describing salmon populations. We emphasize the importance of describing survival characteristics in terms of both capacity and productivity and propose to measure diversity in terms of the ability of the environment to support a multitude of salmon life history patterns. We do not address the fitness of the remaining salmon genomes - rather we look at the ability of the habitat to support diverse life histories.

The concept of salmon ***performance*** is useful in the context of ecosystem analysis generally and in salmon management specifically. As we define it, salmon ***performance*** is a description of the ecosystem within which the salmon completes its life cycle. It tells us how many salmon life histories the habitat can support and how well it supports them. To the extent that salmon is an indicator of the biological integrity of the ecosystem, this information is useful to environmental stewardship in the broad cultural and economic sense. It is of interest to ask: what does the ecosystem look like through the eyes of the salmon? We use the term ***performance*** extensively in this paper. In general we use it to mean the ability of an ecosystem (or watershed) to provide economic, cultural, aesthetic and other values on a sustainable basis. If salmon are an indicator of ecosystem ***performance*** the implication is that the ***performance*** of salmon (in terms of capacity, productivity and diversity) in some, albeit limited, way describes the whole system. When we measure the ***performance*** of the ecosystem "through the eyes of salmon" we assess its ability to support salmon life histories.

The concept of performance is also useful in understanding and managing salmon recovery. Our performance measure has three components: capacity, productivity and diversity. The first two are simply the density dependent and density independent components of survival. We define diversity in terms of life history patterns; and, since this is a departure from the traditional genetics focused definition, we will review the history of the stock concept as a tool for managing salmon diversity. The purpose of this review is to place the habitat life history approach into context, and also to suggest that this approach may provide a better way to set priorities for actions to support diversity. The review of salmon diversity is Part 1 of this paper.

Life histories are defined in terms of coordinates in time and space. They identify when and where the salmon pass through each stage of life. In order to describe the ability of the habitat to support different life histories, we need to incorporate variations through time, space and life stage. This way of describing salmon stocks, their diversity and survival is different from the conventional approaches. In Part 2 of this paper we take a closer look at the components of the performance measure and show how they are integrated across the time-space defined 'game-board of life' -- where survival is the object and capacity, productivity and life history diversity are the variables.

Incorporation of life history diversity as part of the performance measure raises a question of practicality. How do we cope with the complexity' that goes along with simultaneously addressing requirements of multiple population segments? How do we visualize the potential consequences of different actions for the many different life history patterns? One intent of this paper is to show that there are ways to approach the complexity that lead to useful guidelines for management of salmon and their environment. We argue that a performance measure exists that is: a) consistent with our understanding of the ecosystem -- i.e. has a supportable conceptual framework; b) indicative of population abundance and persistence prognosis; and c) useful to decision making and evaluation.

[1] The complexity we refer to is complexity in a dimensional sense (greater fragmentation of life history, time and space) not in a conceptual sense.

PART 1 - HISTORICAL PERSPECTIVE OF DIVERSITY

For two thousand years after Plato western scientists believed that variations observed in nature were errors. Observed variations were explained in this way: they were like the varying shadows on a wall projected from a solid object by the flickering flames of a fire. The essentialists who followed this line of reasoning believed that the variation we see in nature was like the shadows on the wall, and that the solid object was the essence of things, the reality of all organisms. Essentialists believed that means, such as average height in humans, were real measurements of the "essence" of man. The averages were real, and individuals who varied from those averages were errors -- distortions like the shadows on the wall (Mayr 1982). In the nineteenth century some scientists, and particularly animal breeders, began to realize that sexual reproduction produced individuals that were different from each other and that those differences were real. Breeders could select for certain beneficial traits or variations in domestic animals. Once scientists recognized that averages were the constructs and variation was real, the basis for thinking about populations was established. This new way of looking at biological variation and species was called population thinking (Mayr 1982).

With population thinking, species were no longer invariant types. They became mosaics of populations where each population could be different from the others, and the individuals within a population could also show variation. This concept was a major advance in biology. It was this shift that gave Darwin the point of view he needed to see the struggle for existence taking place between individuals, rather than species. Population thinking provided the conceptual framework needed for Darwin's work on natural selection (Mayr 1982).

Populations are self-sustaining breeding groups of a particular species that maintain some reproductive isolation from other breeding groups. Population defined in this way is a real biological phenomenon. However, ecologists and fishery managers often define populations as all the plants or animals in a given study or management area. Under this definition, the population may not be a self-sustaining unit **but** rather an abstraction, an artificial construct. The distinction in the two views of populations has important implications to salmon management which, in turn, has implications to the identification of stocks.

Fishery biologists recognized population thinking earlier than biologists working in other areas. Population thinking has undergone greater development in fisheries than any other field of biology (Sinclair 1988). Two European biologists, Heinke and Hjort, are credited with identifying populations and shifting the focus of fisheries from species to populations. Heinke demonstrated through convincing statistical techniques that the Atlantic herring was comprised of a number of self-sustaining populations. His population concept was extended by Hjort to Atlantic cod and haddock (Sinclair 1988). Sinclair and Iles (1989) place salmon at the upper end of a continuum of population richness among fish species. Salmon migrate to individual rivers where they spawn in isolated breeding groups creating this richness of populations.

Juvenile salmon migrate from nursery rivers to the ocean where they rear in groups of mixed populations. The exchange of genetic material between generations is largely, but not entirely, limited to members of the population that home back to the natal stream to spawn. Adult eels, on the other extreme of the population richness continuum, migrate to a common ocean spawning area in the sea. The immature eels leave the sea and rear in individual rivers (Sinclair 1988).

Although spawning adults are isolated during reproduction in the population rich species, isolation need not continue throughout the entire life history. Immature fish from several salmon populations might rear in the estuary and ocean in mixed aggregates. The mixing of salmon populations in the ocean has important management implications. When mixed populations of salmon are harvested in the ocean, the weaker population may be over harvested resulting in low seeding levels in freshwater habitats. Conversely, reproductive isolation means that harvest of the individual populations at the river mouth during the spawning migration will not impact neighboring populations.

THE STOCK CONCEPT IN PACIFIC SALMON

The high economic value of salmon, and the fact that they are easy to observe as they migrate into fresh water from the ocean, has promoted extensive study of the species. Because they were easy to observe by even the nonbiologists, the population structure of salmon was recognized earlier than reported in the scientific literature. As early as the late 1700's colonists observing salmon in rivers of New England recognized that fish from individual rivers possessed unique characteristics (Dunfield 1985).

Not long after Pacific salmon came under commercial harvest, careful observers on the west coast also recognized that Pacific salmon from different rivers were different. R.D. Hume, who operated canneries in California and Oregon and was an early proponent of the artificial propagation of salmon, observed in 1893:

> ***The fact that in rivers which enter the sea within a few miles of each other, as well as the different tributaries of the same river, the fish (salmon) will have local characteristics which enable those who are familiar with the various streams to distinguish to which river or tributary they belong....***
>
> ***. . ..I firmly believe that like conditions must be had in order to bring about like results, and that to transplant salmon successfully they must be placed in rivers where the natural conditions are similar to that from which they have been taken (Hume 1893).***

However, biologists did not quickly accept the concept that the species of Pacific salmon were comprised of distinct stocks. During the early decades of this century, when European biologists were beginning to recognize the existence of population structure in fishes, biologists in the Northwest were debating whether salmon returned to their home stream to spawn, i.e., whether the salmon species were comprised of individual populations. It was generally thought that the spawning populations of salmon were genetically uniform and that observed differences between salmon in different rivers were attributed to the effects of the environment (Ricker 1972). After reviewing the results of early tagging experiments which supported the hypothesis that Pacific salmon homed to their natal stream, Rich (1938) concluded that the species of Pacific salmon were divided into local populations. He stated:

> ***In the conservation of any natural biological resource it may, I believe, be considered self-evident that the population must be the unit to be treated. By population I mean an effectively isolated, selfperpetuating group of organisms of the same species regardless of whether they may or may not display distinguishing characters, if present, be genetic or environmental in origin. Given a species that is broken up into a number of such isolated groups or populations, it is obvious that the conservation of the species as a whole resolves into the conservation of every one of the component groups; that the success of efforts to conserve the species will depend, not only on the results attained with any one population, but upon the fraction of the total number of individuals in the species attained in the species that is contained within the populations affected by the conservation measures (Rich 1938).***

Since Rich's statement regarding the importance of populations in the conservation of Pacific salmon, biologists have accumulated a large amount of evidence that documents variation between salmon populations from rivers separated by large distances and variation at finer scales within a single watershed (Taylor 1991).

The conservation of local populations or stocks of Pacific salmon and the preservation of their genetic resources is an important management goal (Riggs 1990 and Altukhov and Salmenkova 198 1). Implementing conservation measures that achieve that goal is not simple or easy. The extinction of a population can represent an irreversible loss of genetic diversity. This sobering fact should encourage managers to give evidence of local adaptation -- even circumstantial evidence -- the benefit of the doubt when setting stock boundaries. However, stock boundaries can have critical impacts on management programs. Narrowly defined stock boundaries complicate harvest management in marine areas where populations are mixed. The development of hatchery brood stocks for supplementation programs is made more difficult if stock boundaries are narrowly defined.

The need to conserve biodiversity contained in the individual stocks and the management problems caused by narrowly defined stocks have created two strongly held positions on stock boundaries. The positions are characterized as "lumpers or splitters." Lumpers tend to see few stocks and a simple population structure. Splitters see Pacific salmon as population rich with a complex population structure. Driving this debate is the underlying question: How much weight should we give to management strategies, as opposed to biological criteria, when setting stock boundaries?

HIERARCHICAL STRUCTURE OF SALMON STOCKS

Biologists are currently engaged in a debate as to how the boundaries of stocks should be established (Riggs 1992). To a large degree, the debate is driven by the search for the "ideal" stock designation, i.e., a stock whose boundaries represent a meaningful biological level of organization for conservation while at the same time not complicating existing management strategies.

There is no single stock designation that meets all biological and management criteria. The species of Pacific salmon are organized in a hierarchical structure (Currens et al. 1991 and Riggs 1992). The biological units in the hierarchy (species, metapopulation, population, subpopulation, individual) and their associated geographical units (region, basin, river, stream, headwater tributary and redd) persist for different time intervals (Currens et al. 1991). To conserve the genetic diversity between and within stocks, managers must match the appropriate level in the hierarchy to the management activity. The appropriate level in the hierarchy is the most inclusive population/geographic unit for which a management action will not cause the loss of genetic diversity contained in less inclusive groups (Currens et al 1991).

METAPOPULATIONS

Consistent with the hierarchical structure of populations is the concept of metapopulation which is defined as a population of populations distributed over habitat fragments and interconnected by colonizing individuals (Opdam 199 1). Metapopulations distributed over isolated habitats are interconnected by patterns of gene flow, extinction and recolonization (Lande and Barrowclough 1987). In a metapopulation, small populations in marginal habitats might blink out of existence from time to time. The habitats are recolonized by the larger source populations within the metapopulation. The extinction frequency of all but the smallest populations is probably on the order of hundreds of years and is associated with catastrophic events like fire or prolonged drought.

LIFE HISTORY DIVERSITY

Life history diversity in anadromous salmon is the variable use of rearing and migrating habitats through time and space. Diverse life history patterns dampen the risk of extinction or reduced production in fluctuating environments (Den Boer 1968). Salmon must contend with annual fluctuations in climate as well as long-term climate cycles. In addition, the physical habitat of rivers is subject to natural disturbance through landslides, fire and channel shifts during floods.

Timing of the use of habitats is a life history trait important to the persistence of salmon populations, and there is evidence for genetic control over juvenile and adult migration timing (Gharrett and Smoker 1993 and Carl and Healey 1984). The potential and realized life histories of a stock theoretically reflect its adaptability -- the ability to survive in fluctuating environments (Weavers 1993).

The general observation by Thompson (1959) that salmon life histories are comprised of a chain of habitats with a favorable spatial/temporal distribution is an important concept that needs to be included in the process of defining and describing stocks. The point here is that stocks cannot be identified independent of their habitat, and life history makes the connection between salmon and habitat.

Healey and Prince (1995) conclude that the population and its habitat form the appropriate conservation unit and that population diversity depends upon habitat diversity. If life history forms the connection between the population and its habitat, it seems reasonable to focus management attention on this connection. Human activities have altered or destroyed these connections; and, if we hope to keep the salmon, we must protect and enhance what remains. In order for salmon populations to persist, their life history pathways through the habitat must remain connected. We conclude that a measure of ecosystem performance based upon the ability of the environment to support connected salmon life histories is appropriate.

PART 2 - PERFORMANCE

Some definitions of terms are in order. We define a ***life history pattern*** as a population segment composed of individuals that pass through the same locations at the same time in completing their life cycles. Their path through time and space is their ***life history trajectory*** (or ***pathway).*** The scales by which time and space are incremented define the distinct life history patterns. For the purpose of this paper we assume that distinct life history patterns are identifiable. We make no assumption about the genetic components of life history -- multiple life histories patterns may occur within a breeding unit. However life history patterns must come to closure (Sinclair 1988) at some level in the population hierarchy. This means that a life history pattern must for example define a large enough spawning area that most spawners were themselves hatched in that area.

A CONCEPTUAL FRAMEWORK

By the term performance we mean an observable expression (description) of the characteristics of an ecosystem. Typically concepts like function, structure, complexity, connectivity and self-organization are used to describe ecosystems. We have chosen a narrower perspective, where we describe a portion of the ecosystem from the point of view of a single indicator species. The criteria for selecting indicator species are not a topic of this paper; instead we assume that if an appropriate indicator species exists, its perception of the system is useful to our understanding of ecosystem performance. The examples we use in the following are based on salmon as an indicator species (Figure 1). We define performance of the system on the basis of survival conditions (as we understand them) for salmon.

Salmon survival along the life history trajectory is a function of environmental quantity and quality. A common and sometimes useful way to incorporate quantity and quality is through the concepts of productivity and capacity. Each stage along the life history trajectory can be described in terms of its productivity and capacity relative to the life stage present. Any life history trajectory can thus be described in terms of a sequence of productivity and capacity values (Paulik 1973; Moussalli and Hilbom 1986). We refer to this sequence of values as the ***performance profile*** of the life history trajectory. The performance profile is a function of the quantity and quality of the environment across the time-space range of the species and of the particular trajectory that the life history pattern follows across this range. The quantity-quality characteristics across the time-space range of the species comprise the ***relative survival landscape.*** It has time, space, and productivity (or capacity) axes, and it is specific to species, race and life stage.[2] We describe the ***performance potential*** of this landscape in terms of its ability to allow a multitude of life history trajectories to persist and abound. This

[2] The expression “species, race and life stage” is used throughout this paper to suggest a partitioning of salmonids into groups that are homogeneous with respect to their response to the physical and biological environment.

conceptualization of salmon life history trajectories traced across a survival landscape forms the framework for the discussions that follow.

The framework outlined above views an ecosystem, from the salmon's perspective, as a web of trajectories, each with its own sequence of productivity and capacity characteristics. Performance is a description of the structure of this web -- the number of strands, their "elasticity" and "thickness." It is a composite of all possible pathways available to salmon in completing their life cycle. Each trajectory in this web is a pathway through the time-space environment that comes to closure. It describes the smallest self-reproducing unit (Sinclair, 1988).

A defining characteristic of a ***closed trajectory*** is that its cumulative productivity is greater than one (i.e. at low density a parent produces, on average, at least one offspring that survives to reproduce). Another characteristic is that it is consistent with known or hypothesized salmon behavior.[3] Many other pathways could be identified where, under different environmental conditions, life history trajectories could come to closure. The performance of past and future environments, for example, can be hypothesized by identifying and describing the trajectories that could persist in those environments.

The concepts of present and potential performance are akin to Warren's notions of performance and realized capacity (Warren et al. 1979; and Frissell et al. in press). While Warren et al. use the term performance to mean observable characteristics of the system at all levels of biological organization, we focus on a subset of performance outcomes. We use a population survival model as a filter through which we express performance along a salmon life history trajectory (RASP 1992). We next look more closely at some of the terms and concepts that define our framework.

PRODUCTIVITY

Moussalli and Hilbom (1986) show that the Beverton-Holt survival function[4] has some very convenient mathematical properties. This is one reason we use it to illustrate our performance measure; another is its familiarity and broad use in population dynamics. The concepts we describe are largely independent of the choice of survival function. Moussalli and Hilbom (1986) and Hilbom and Walters (1992) provide a more extensive discussion of multi-stage production functions and their properties.

Productivity is the density independent survival parameter. It measures the "elasticity" of the trajectory -- its ability to persist. It is determined by environmental quality characteristics that regulate survival and reproductive success at low abundance. Methods for estimating productivity along a life history trajectory have been described by Mobrand et al. (1995). Productivity is the element that determines sustainable harvest rates (Hilbom and Walters 1992).

---

[3] We make the assumption that a finite number of distinct salmon life history patterns exist and can be identified.

[4] Beverton and Holt (1957) developed a mathematical model often referred to as a Spawner-Recruit function, which they derived from an assumed relationship between survival and density.

Productivity is the component of survival at each life stage that operates independently of population density. It is the largest expected survival.

CAPACITY

Capacity, in the conventional population dynamics sense, is a parameter that regulates potential abundance. It is a function of both environmental quantity and quality. In our framework we think of it as the thickness of the trajectory -- a thickness that may vary along the trajectory. The capacity (as well as productivity) at any stage along the trajectory is specific to species, race and life stage. In other words there are many relative survival landscapes within the same time-space range, each subscripted by the species, race and life stage to which it applies. This potential profusion of landscapes is constrained and integrated by the environmental attributes that describe each location along the trajectory (Figure 1).

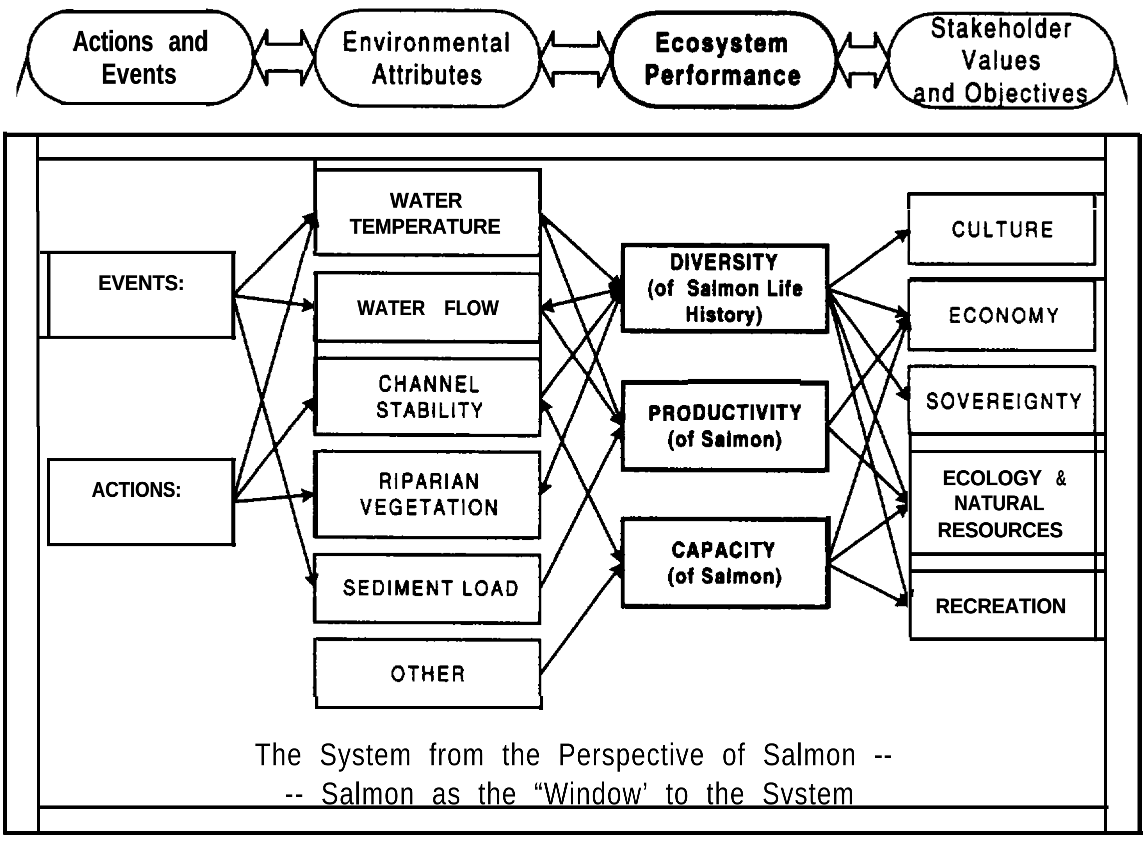

Figure 1. **Salmon as an indicator of ecosystem performance. The general conceptual framework portrays societal values as a consequence of actions and events acting upon the environment and through the performance of the ecosystem. Salmon can be studies in the context of this framework. A case can be made that salmon is an indicator of ecosystem performance**

CUMULATIVE PRODUCTIVITY AND CAPACITY

The ***cumulative productivity*** of a trajectory is the product of the productivities of all component life stages (Moussalli and Hilbom, 1986):

$$P = \prod_{i=1}^{n} p_i$$

where P is cumulative productivity and p_i are productivities for each of n life stages.

Note that P is independent of the capacity parameters. When the cumulative productivity of a trajectory exceeds unity, we say that it is closed. Figure 2 shows the effects of changes in cumulative productivity and capacity on recruitment and surplus production using Beverton-Holt Spawner-Recruit curves for a low productivity population. The purpose of Figure 2 is to highlight the point that productivity improvements enhance population resilience and surplus production regardless of capacity bottlenecks. This is a critically important point because all too often the incorrect assertion is made that habitat improvements are of little value until bottlenecks (in capacity) are removed (Reeves et al. 1989; Hubert and Fight 1991). Bottlenecks, or limiting factors, are associated with constraints on capacity only. For weak populations, productivity improvements at any life stage will increase cumulative productivity and, consequently, surplus productivity. The approach we propose is different from the traditional limiting factor analysis. It takes into account productivity as well as capacity and evaluates them in the context of the full life cycle. The bottleneck metaphor addresses abundance, not productivity.

Cumulative capacity is the capacity parameter in the Beverton-Holt spawner-recruit function, which incorporates the full life cycle. The unit of measurement of cumulative capacity depends on the life stage chosen to define the end of the life cycle loop. Here we shall assume that the life cycle ends (and begins) with spawning.[5] Moussalli and Hilbom (1986) show that "if the life history of a population consists of a sequence of density-dependent stages linked by density-independent survival rates, and if the density- dependent stages take the form of the Beverton-Holt stock and recruitment curve, then a single Beverton-Holt curve will describe the entire life history." They derive the cumulative capacity parameter as a function of productivities and capacities of the componentlifestages:

[5] The choice of start-end point for the trajectory is not arbitrary. It should be selected so that the cumulative capacity (which is the parameter affected by this choice) is informative relative to objectives and values. A strong argument can be made for selecting as the 'currency' for the cumulative capacity the number of adults that survive to begin spawning. This currency is familiar to managers and fishermen; it is the smallest number of individuals alive of any cohort; it represents the end of a generation; and it is the most 'natural* choice for expressing cumulative capacity.

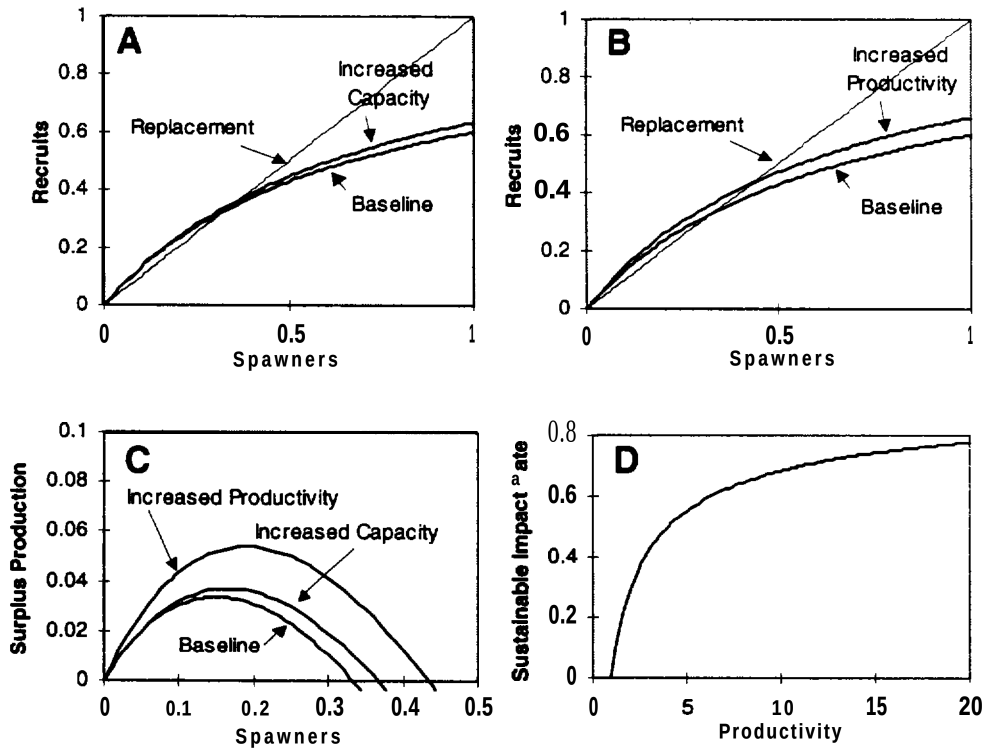

Figure 2. **Sensitivity of recruitment to productivity in the Beverton-Holt function. Graphs A, B and C compare a 10% increase in capacity with a 10% increase in productivity. The response to productivity (B) is greater than to capacity (A). Graph C shows further the productivity increases surplus production more significantly. Graph D shows how the sustainable rate of removal increases rapidly with productivity near the productivity value of one.**

$$C_n = \frac{P_n}{\sum_{i=1}^{n} Pi / c_i}$$

where C and $\boldsymbol{P}$ are cumulative, P_i are products of productivities for stages 1 though $\boldsymbol{i}$ and c_i are life stage capacities. Note that cumulative capacity is a function of both capacities and productivities. The effect of a change to a specific life stage capacity therefore depends upon the capacities and productivities in all life stages. It is affected by the performance profile of the trajectory. This is very different from the situation with productivity, where the cumulative impact is simply proportional to the life stage specific impact. A change in productivity for any life stage induces a proportional change in overall productivity, but this is not the case for capacity.

The behavior of the Beverton Holt survival function[6] therefore suggests that **populations with different performance profiles experience the same changes in capacity differently.** Furthermore, under our framework the same environmental changes may induce different changes in the capacity parameter, depending upon species, race and life stage affected. This implies very strongly that the conventional approach, where cumulative impacts are assumed simple and linear, must be reevaluated. Bella (1995) refers to the linear presumption as a fundamental misconception that hinders management and assessment of activities affecting salmon in the Pacific Northwest. Our framework supports his claims. We need a different way to understand and compare the effects of different sets of activities on salmon population aggregates.

DIVERSITY

Persistence, abundance and distribution of salmon populations can be altered or lost through changes in any or all of the three components of performance. Loss of productivity affects survival and persistence directly -- a loss at any stage accumulates multiplicatively. Reduced capacity can create bottlenecks that limit abundance. This section will take a closer look at the third component -- diversity.

The life history trajectory based framework allows us to formulate and test hypotheses about diversity. Life history diversity is the salmon's solution to a changing environment. Diversity is lost when life history trajectories become disconnected. Disconnected trajectories cannot carry salmon through completion of their life cycles because their cumulative productivities have fallen below one. Disconnected trajectories are a liability to salmon populations. Confined to fewer connected trajectories, their opportunities for spreading the risks associated with environmental instability are reduced. Disconnected trajectories are also a drain on survival due to those opportunistic salmon that unwittingly become trapped in terminated trajectories and perish.

In the framework we define diversity as the multitude of life history trajectories with cumulative capacity greater than one. By describing each trajectory in terms of its productivity and capacity we can profile the collection of all trajectories available to a population. Hypotheses about diversity as a cause, or a remedy, for decline of salmon populations can be formulated in these terms. Frequently historical data allow us to postulate the role of diversity loss in the decline of salmon. Figure 3 is an example from the Grande Ronde Basin in Oregon showing four historically very productive life history trajectories (templates) compared to two remaining and weak trajectories (patients) (Mobrand et al., 1995).

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[6] It also applies to the Ricker and other production functions as Moussalli and Hilbom (1986) point out.

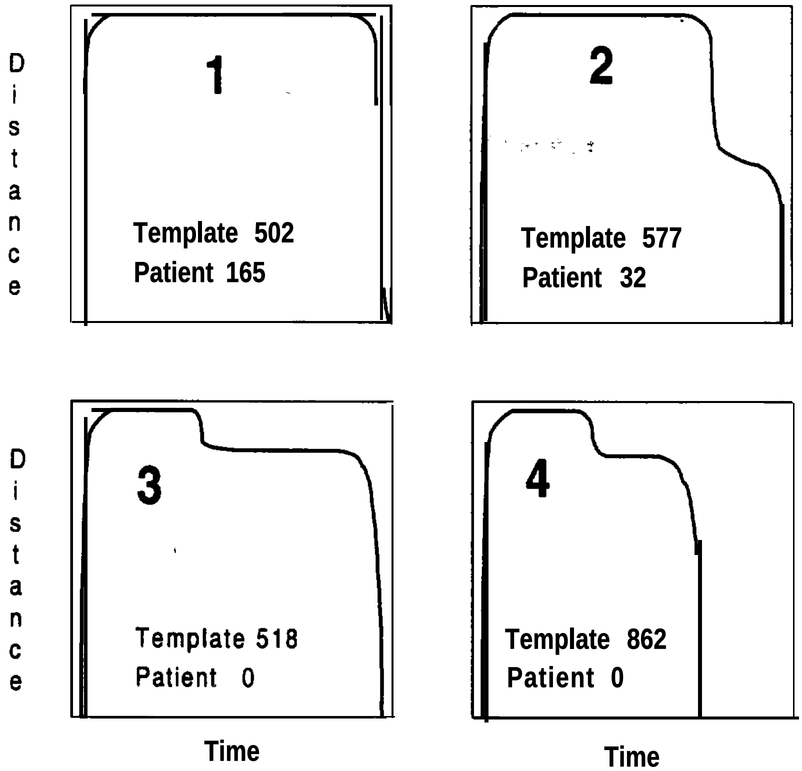

Figure 3. Life History Diversity Example from the Grande Ronde River, Oregon. Four spring chinook life history trajectories are displayed on a time (horizontal axis) and space grid. They trace prespawners entering the watershed at the lower left; moving upstream to spawn; rearing of the next generation; and migration downstream by smolts to exit the watershed at the lower right. Relative productivities (as smolt/prespawner) are indicated for Template (historic condition) and Patient (present condition). The information indicates that all four trajectories were viable historically, but today only trajectories 1 and 2 can persist. Observed spring chinook usage of this watershed corroborate these findings. From Mobrand et al (1995).

Life history diversity adds a new dimension to performance that is missing in the traditional paradigm which focused on production and capacity. It brings habitat availability and connectivity over time and space into a clearer focus. We have portrayed productivity and capacity as the elasticity and thickness of the life history trajectory strands. It is tempting to use a medical analogy as a metaphor for all three dimensions of our performance measure: the trajectories are like the blood vessels that supply an organ -- the multitude, elasticity, and thickness of these vessels affect the function of the organ.

POPULATION HIERARCHY

In our framework, a life history trajectory represents the smallest (relative to the adopted time-space scale) closed life history cycle with cumulative productivity greater than one. Large watersheds support many trajectories which may overlap (in time-space-life stage), to varying degrees. The dendrogram in Figure 4 represents a hypothetical family of life history trajectories composed of nine distinct patterns. The distance measured along the Y-axis is analogous to the

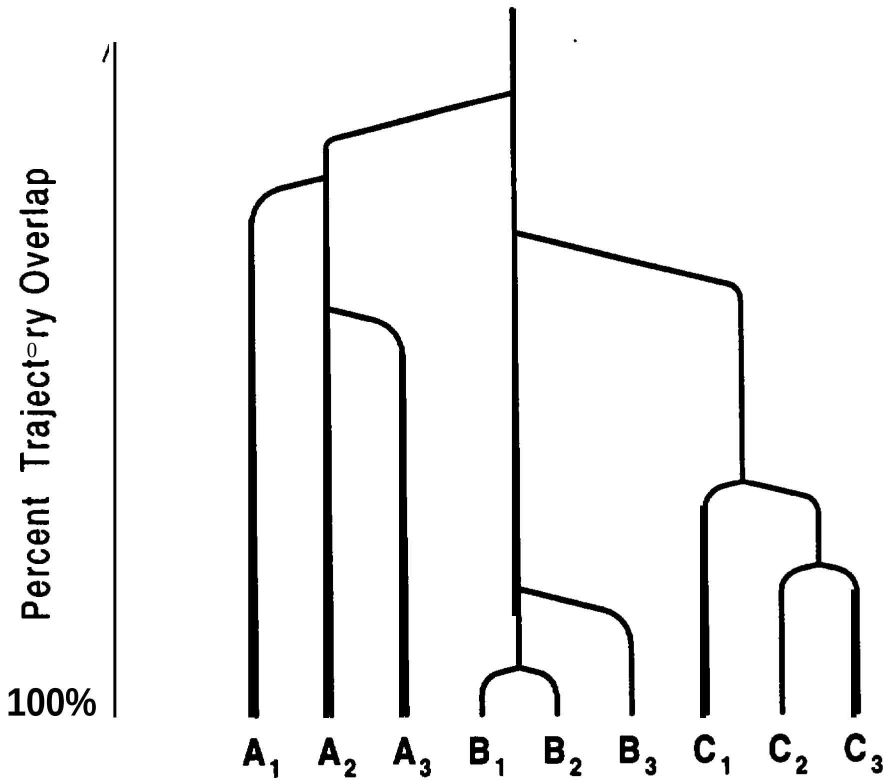

Figure 4. Conceptual relationship between life history trajectories. Life history trajectories of salmon can be organized hierarchically on the basis of their coincidence in time, space and life stage. Clusters (represented by letters) in this hierarchy may represent similarity in both geographic distribution and life history timing characteristics

degree of overlap among the trajectories. This is an environmental depiction of the system that supports the life history trajectories. Whether or not a given trajectory can support a salmon population is primarilyan environmental question[7]. The extent to which these trajectories are populated with salmon is largely a genetics question: do populations which are capable of taking advantage of the trajectories exist? We do not address this question here. Instead we argue that unless the trajectories exist, the genetics question is moot.

In the hierarchy described in Figure 4, performance can be described in an analogous way at any level, from the aggregate of all salmon trajectories in the basin to an individual time-space-stage element of any trajectory. The framework and its derived performance measure serve to integrate all environmental components relevant to salmon survival in the basin. We can “zoom in” on a stream reach and “zoom out” to the full basin view to see similar representations of performance and know that they are based upon a consistent and comparable set of observations. The whole has become the sum of its parts. We have a conception of cumulative effects that reflects the complex, non-linear reality of the ecosystem.

[7] Productivity has genetic components (fecundity, maturation rate, and sex ratios) as well as strictly environmental ones. Here we assume only that these components can be estimated and that by definition [of a trajectory] they remain constant within a trajectory.

There is one further organizational (taxonomic) element of the framework that must be explained. We envision the life history trajectories as traces across a relative survival landscape. This landscape is, in fact, composed of many layers; the trajectories may shift between layers (Figure 5). The layers in the landscape represent the variety of ways in which salmon of different species, races, and developmental stages perceive and respond to the same conditions. Thus, for any location in the time-space grid of the salmon’s range, there is just one set of environmental conditions.’ This set, however, induces several different productivity and capacity parameters corresponding to species, race, and life stage. There might be one set for fall chinook spawning, another for sockeye fry colonization, and so on.

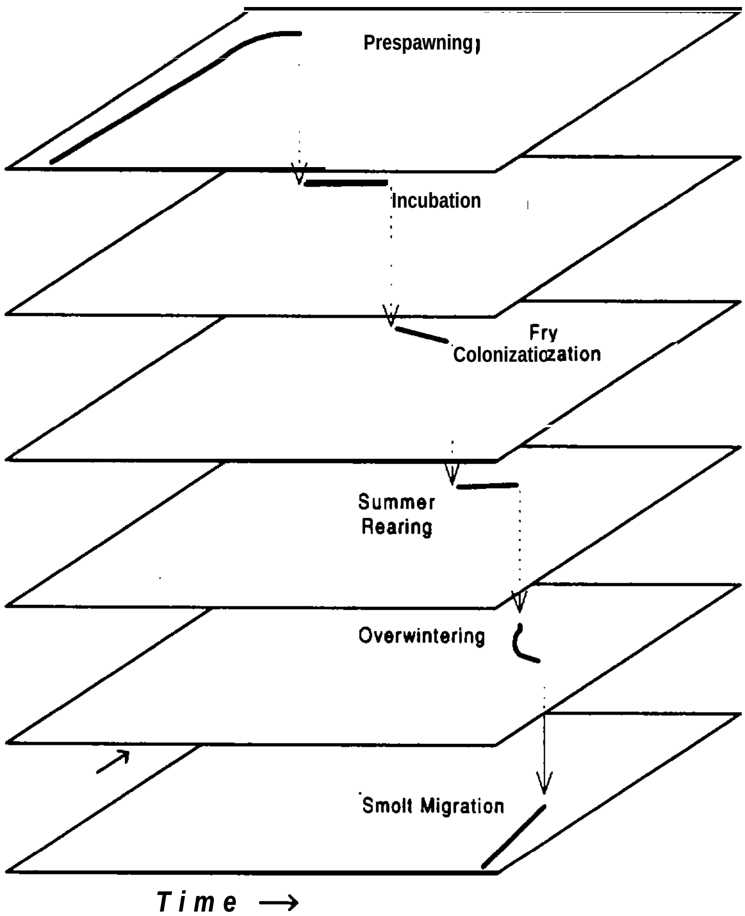

Figure 5. Visualization of a portion of a salmon life history. Each plane represents the survival conditions (performance) of one life stage. The colored line shows a hypothetical life history pathway. Data describing capacity, productivity and environmental attributes are organized and displayed on location vs time grids (the planes) and analyzed from the salmon perspective by tracing the values along life history pathways (colored line).

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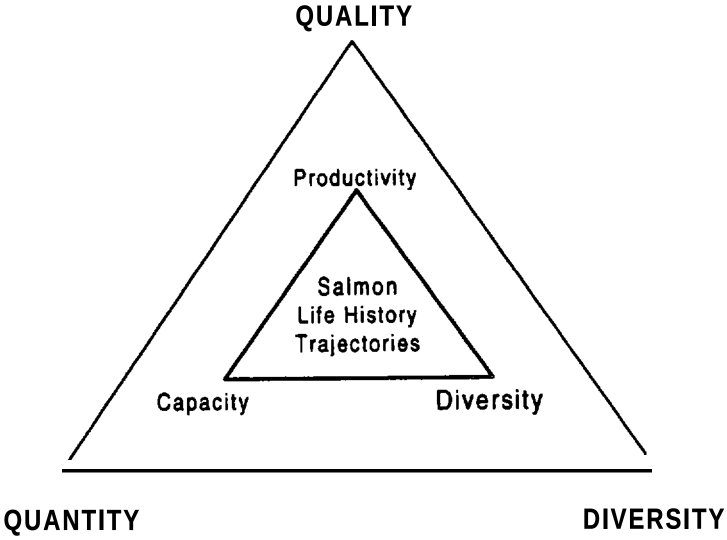
[8] This assumption does not preclude variability. The environment at a given time and location may be described in terms of both the means and variances of a set of attributes.

PERFORMANCE-VISUALIZATION-COMMUNICATION-UTILITY

In our framework the elements of productivity, capacity and diversity are inextricably linked (Figure 6). They are the dimensions of performance 'that we use to obtain a partial image of the ecosystem. Like any model or paradigm, this framework is no more than a tool, the utility of which ends when a better one is found. We make no claim that it represents truth, only that it is more useful than the currently available alternatives. It is noteworthy also that although this paper presents mainly theory, the approach has been developed in practical detail (Lestelle and Mobrand, in progress) and portions of it have been applied in the field (Mobrand et al, 1995).

Figure 6. An Ecosystem Performance Measure. The purpose of this illustration is to highlight the points that a) the three components of the performance measure are closely related



to one another and b) performance measures derived from analysis of salmon life histories are a partial indicator of system performance

If the performance of each trajectory in Figure 3 is summarized by its cumulative productivity and capacity, then the historic and present performance for the whole system might be summarized as shown in Figure 7. This picture shows the three components of performance simultaneously. This performance measure is not a simple numeric index that can be ranked in order from smallest to largest. Rather, the salmon populations of a watershed and its many manifestations (potential performances) are not conducive to being transformed into a single index. Such simplification is inconsistent with our understanding of the structure and function of ecosystems and with the values we seek to derive from them and therefore cannot be useful to decision making or to assessment of the effects of our actions.

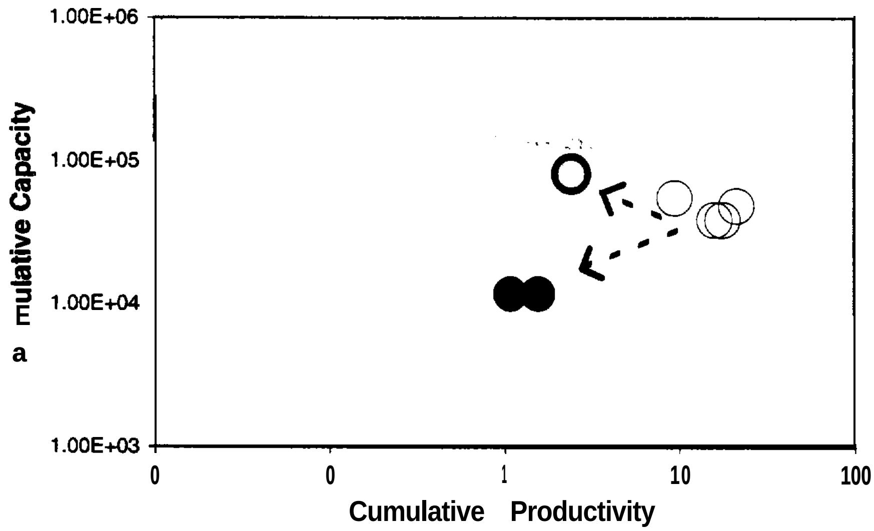


Figure 7. Visual representation of performance for a hypothetical salmon population. Filled circles represent present performance, open circles historic performance (the grey filled circle is a present trajectory that incorporates a hatchery as one stage). The number and location of points on this graph indicate performance of the population aggregate

We suggest that the performance measure proposed here is: a) based upon a supportable conceptual framework; b) indicative of population abundance and persistence prognosis; and c) useful to decision making and evaluation. In the examples that follow we attempt to show that this measure can contribute to the understanding of how actions affect values such as salmon enhancement objectives.

The performance measure we propose and the conceptual framework from which it is derived are not predictive in the traditional sense. They constitute a model for understanding and for learning. Our ability to make decisions that lead toward achievement of our objectives cannot be predicated upon our ability to predict outcomes of our actions in terms of numbers of salmon produced by a specified time. Instead we must use our understanding of the system (i.e. the conceptual framework) to make decisions and take actions that increase or decrease the likelihood of returning salmon in greater numbers.

The performance measure is an indicator of how favorable the environment is for salmon to persist and abound, not a predictor of how many will return and when. Such predictors are unreliable; and, consequently, performance measures based upon short term abundance responses are poor guides to decision making (Lichatowich and Cramer 1979). This does not mean however that objective setting cannot or should not be specific in terms of numbers, distribution and time frames. Specific objectives are needed to guide priorities and investments. Management actions based upon the conceptual framework of understanding need the direction provided by a clearly articulated vision of desired future conditions.

CONCLUSION

A premise for this paper is that the framework and performance measures used in watershed management generally, and salmon management specifically, are inadequate. The bottleneck metaphor is cited all too frequently as a basis for discussion. The bottleneck analogy is useful to understanding capacity, but capacity alone cannot explain observed responses of salmon populations to environmental change. An argument can be made that where protection and enhancement of weak stocks is the priority, productivity is a more critical parameter. But a framework built only around productivity and capacity is also not sufficient. It neglects the need for connectivity of habitats that salmon must pass through to complete their life histories. Adding life history diversity as the third component of performance provides the time and space structure needed to deal with connectivity while also allowing for integration of populations where they mingle.

The intent of this paper is to show that discussion of watershed health and salmon performance can incorporate a much greater degree of complexity without loss of clarity. We indeed should include more temporal-spatial detail, more life history complexity, and more watershed specific information.

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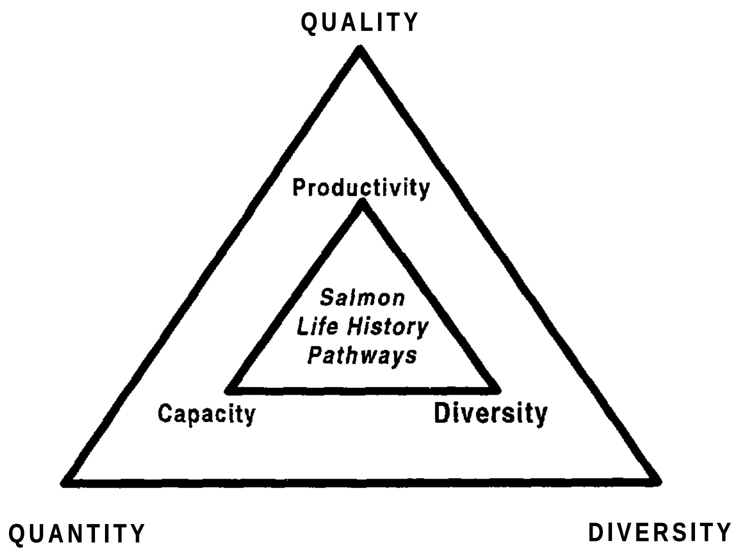

Examples of the Use of a Trivariate Performance Measure

May 1996

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EXAMPLES OF THE USE OF A TRIVARIATE PERFORMANCE MEASURE

A habitat and life history based performance measure was proposed by Lichatowich et al (1995) as a better way of describing salmon populations. The measure differs from traditional approaches in that it includes three variables (productivity, capacity and life history diversity) rather than just one (capacity). The advantage of the traditional approach is that it allows us to order populations linearly, from largest to smallest. The great disadvantage is that it simplifies the description of multifaceted populations to a point where it loses utility. The trivariate performance measure admits a much greater degree of complexity, but in so doing also creates a challenge in terms of interpretation and presentation. The purpose of this paper is to give some examples of how a more complex performance measure can be used to describe and compare populations. We limit our examples to graphical displays; however, we note that more rigorous statistical tools exist for multivariate analysis.

As it becomes increasingly apparent that cumulative impacts of local actions must be a part of the environmental management picture, we are faced with the challenge of understanding and incorporating interactions on many levels. This will require regional information sharing and regional decision making. The trivariate performance measure we describe here and its associated conceptual framework (Lichatowich et al 1995) provides a structure for incorporating nonlinear cumulative impacts (Bella 1995). It is our intent here to show that it is possible to present information in a form that is useful to the decision making process, while both incorporating more local detail and achieving regional integration.

We refer to the companion paper by Mobrand et al (1996) for definitions of terms and detailed descriptions of the performance measures. The three elements, or variables, in the performance measure are: productivity, capacity and life history diversity (Figure 1). These three elements that describe performance are not independent; for example, life history diversity is a direct consequence of the sequence of productivities and capacities along connected pathways through the habitat. In the following we will examine these three elements and their relationship by using a simple model and some graphical displays.

MODELING RESULTS

We model a simple scenario to illustrate some of the properties of the performance measure. Figure 2 shows a partition of a salmon life history into four life stages. Survival at each stage is

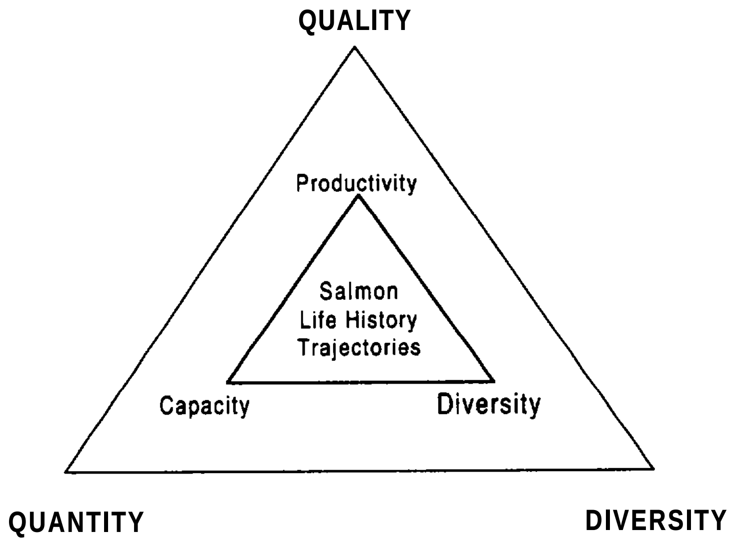

Figure 1. An ecosystem performance measure. The purpose of this illustration is to highlight the points that a) the three components of the performance measure are closely related to one another and b) performance measures derived from analysis of salmon life histories is a partial indicator of system performance.

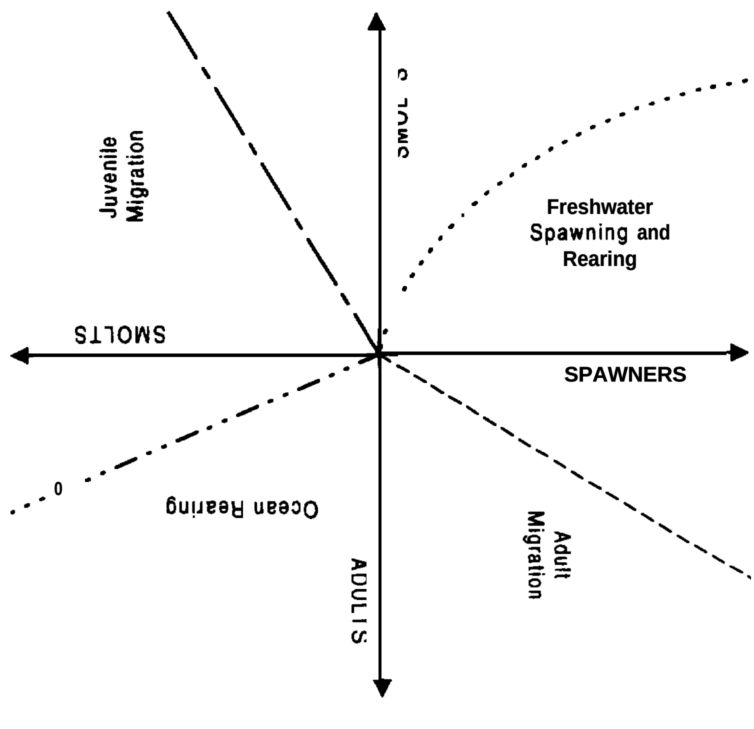

Figure 2. Four stage survival function for salmon. The four stage model used to illustrate the performance measure consists of four separate Beverton-Holt functions. This diagram adapted from Paulik (1973) shows one life stage in each quadrant as the page is turned clockwise. The cumulative production function is also a Beverton-Holt equation.

determined by a Beverton-Holt[1] type survival function (Beverton and Holt 1957) with different productivities and capacities for each stage. We confine our analysis of life history trajectories to these four stages, with the understanding that results can be generalized to much finer scales of resolution. Figure 3 illustrates the trajectory that this four stage life history might trace across the landscape. Adult salmon spawn and their young rear in the headwaters of their native stream in the first stage; juveniles migrate downstream through the estuary and into the ocean in the second stage. Stage three is the ocean rearing phase and stage four the spawning migration of maturing adults. Each stage is associated with a location, a time period, and a set of productivity and capacity parameters. All members of a life history pattern inhabit the same life stage at the same time and place -- they coincide in time, space and life stage. The productivity and capacity parameters of each life stage are linked to habitat quantity and quality characteristics in the time-space grid, and those characteristics are in turn related to actions (man's) and events (natural) (Lichatowich et al. 1995; Mobrand et al 1995). In the following we will take a closer look at the implications of the productivity/capacity characteristics across this simple landscape and the trajectories that a salmon population which is composed of one or more life history patterns might follow.

There are two major steps in the analysis. First, we identify and describe each life history trajectory in terms of capacities and productivities by life stage. All trajectories of the indicator species in the watershed of interest must be described in this way. The procedures for accomplishing this step are described by Lichatowich et al (1995), Mobrand et al (1995) and Lestelle et al. (in progress). Once this step is completed, we have performance profiles for all trajectories based upon a common environmental database and a common set of assumptions. These profiles portray the environment, but they do not incorporate the interactions that occur among populations whose trajectories overlap.

In the second step of the analysis we integrate the individual trajectories. If individual populations were independent of one another, this step would not be necessary. However, life history trajectories do overlap, often very extensively. In those locations in the survival landscape where multiple life histories coincide, ecological interactions affecting survival are likely. These interactions are accounted for in the integration step. This is also where the cumulative impacts of activities and events are incorporated.

What we are looking for in the integrated analysis is a new set of performance profiles which have been corrected for the effects of interactions among populations from different trajectories. These interactions depend upon the abundance that each trajectory contributes to the shared time-space stages. To arrive at a reasonable and useful understanding of the effects of these interactions, we define the adjusted performance profile by the equilibrium condition. Using a model based upon the recursive properties of the Beverton-Holt equations as described by

[1] $\text{Survival} = \dfrac{\text{Productivity}}{1 - \dfrac{\text{Productivity} \times N}{\text{Capacity}}}$, where N is population size.

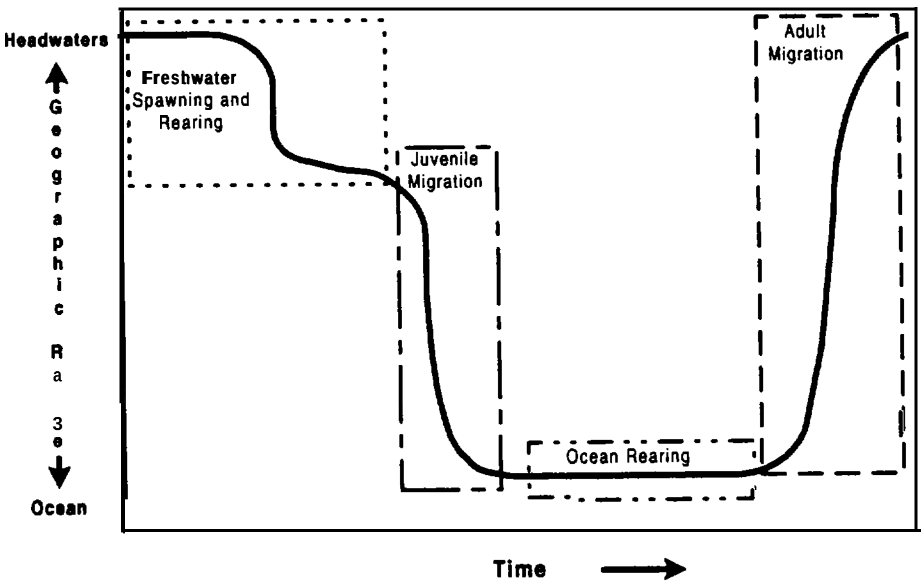

Figure 3. Four stage salmon life history trajectory. Each life stage occupies a range in time and space. Across this range survival conditions will vary with the environmental conditions. The pathway through this range that a salmon may use on its way to successfully complete its life cycle is its life history trajectory. This graph shows a single trajectory as it completes a four stage life cycle. The range covered by the trajectory is also the base plane of the survival landscape. Survival conditions induced by the environment across this landscape determine the survivorship along the trajectory.

Moussalli and Hilborn (1986), we compute the survivorship along each trajectory when all populations come to a steady state equilibrium. In the following we will first examine unadjusted performance profiles and then look at model results of cumulative impacts on the adjusted profiles.

UNADJUSTED PERFORMANCE PROFILES

The performance profile of a relatively small and weak trajectory is shown in Figure 4. Interpretation of a figure like this without benchmarks or reference points is difficult. Lichatowich et al. (1995) propose a method for creating a reference point. Their Patient Template Analysis (PTA) suggests that the historic condition of the population prior to major man-induced ecosystem changes can serve as a reference point in the diagnosis of the present condition. Comparison of performance profiles--present and historic--helps formulate hypotheses about the relationship between environmental changes and salmon abundance and distribution. Historically productive trajectories may have disappeared; the remaining ones altered in capacity and productivity and so on. Figure 5 shows a PTA comparison for a single trajectory. The reduced cumulative performance is the net result of productivity and capacity changes at each life stage.

Another useful reference point is the desired future condition. Objectives can be achieved in a variety of ways - there is no single performance profile for the future condition where objectives

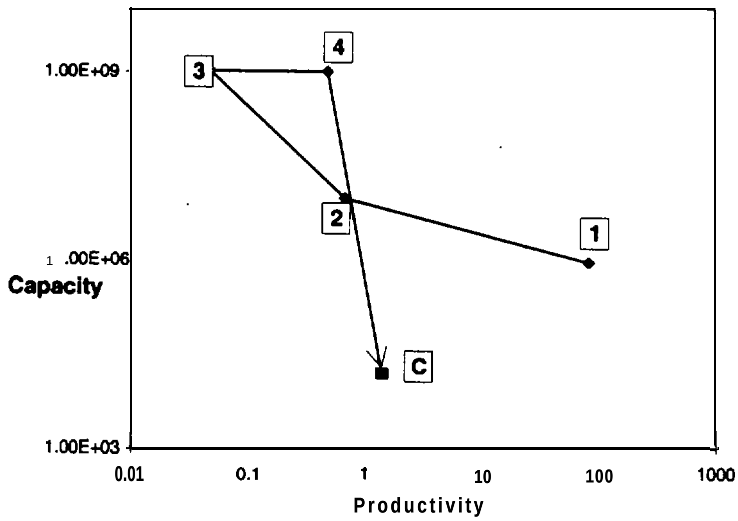

Figure 4. **Performance profile of a hypothetical salmon population. This graph traces performance from spawning and rearing (1); to juvenile migration (2); to ocean rearing (3); to adult migration (4); and finally to cumulative (full life cycle) performance (C). Coordinates for points (1) - (4) give the productivity and capacity for each life stage. Coordinates for point (C) are cumulative productivity and capacity. This simple illustration partitions the salmon life history into four segments only, in applications there will typically be a hundred or more segments with different productivities and capacities included.**

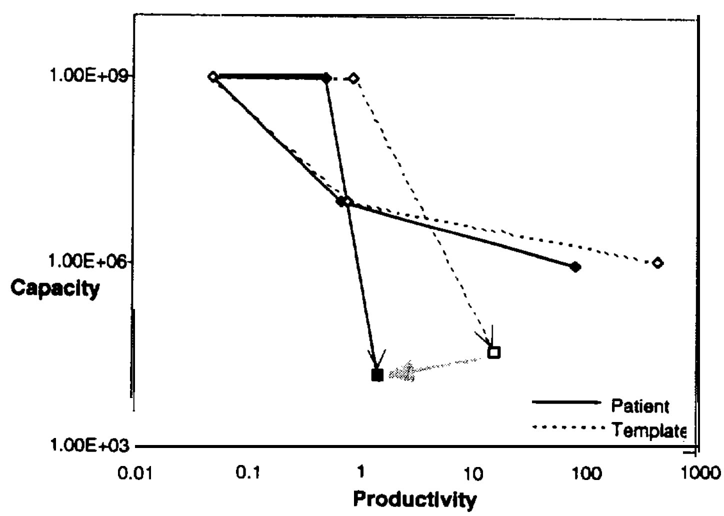

Figure 5. **Performance profiles of patient and template for a hypothetical salmon population. This example suggests a substantial difference in performance between the Template and the Patient. The Template represents the environmental conditions most favorable to salmon along the same life history trajectory. The grey arrow indicate the difference between the Template (potential) and Patient (realized) cumulative performance along this particular trajectory. The Template represents historic potential, it may not be possible or desirable to restore this potential. The Template is of value as a reference point,**

are met. Instead there are several alternatives to achieving similar results. Different performance profiles that lead to similar goals correspond to alternative strategies for management. Each alternative future performance profile can serve as a guide to an integrated strategy for moving toward a desired set of future conditions. Within the context of a PTA the alternatives can be evaluated in terms of ecosystem feasibility -- which ones are consistent with our understanding about what the ecosystem can deliver? The environmental changes necessary to approach the objectives can be described. The utility of the PTA in a decision making context is discussed by Mobrand et al. (1995) in a report on its application to the Grande Ronde model watershed process.

Figure 6 shows one pathway toward an objective defined by the cumulative performance at the end of the path. Several alternatives exist, involving different combinations of life stage productivity and capacity changes. The figure compares the future alternative against the template and the patient conditions.

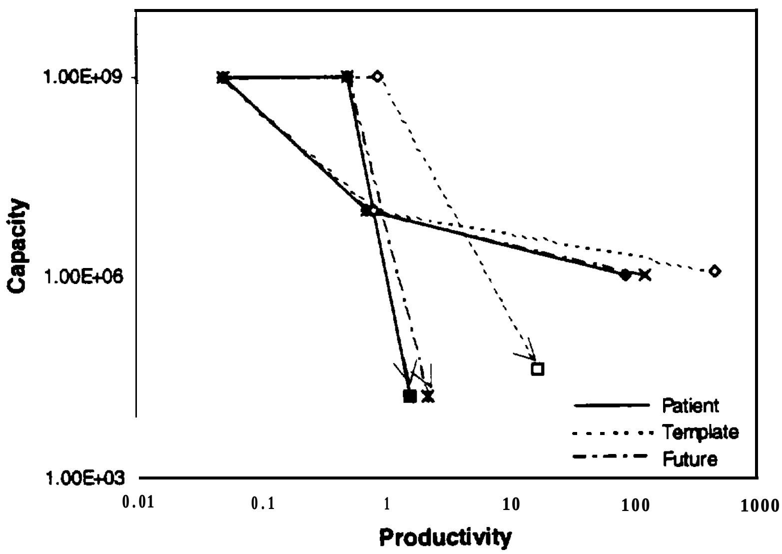

Figure 6. Performance profiles of patient, template and future scenario for hypothetical salmon population. In order to achieve the cumulative performance objective indicated at the head of the "Future" arrow, productivity for the spawning and rearing stage is increased from 85 in the Patient to 120. Similar performance objectives might be achieved through other measures as well.

It is important to keep in mind here that the scenario we are using to illustrate the performance concept is simplified. When we apply this method, we typically partition the life history into hundreds of segments, each segment representing a river reach, a short time period, and a developmental stage of salmon. We find that data describing environmental quantity and quality are often readily available and usually more reliable at this level of resolution. When this information is integrated though the calculation of cumulative productivities and capacities, we obtain a picture of the aggregate that is consistent with the detailed data. Thus, we have an approach that integrates the detail, which we can observe and measure, with the broader watershed or regional picture for any life history trajectory. We will next address the question of interaction among trajectories. This will allow us to integrate all segments of all life histories

PERFORMANCE PROFILES ADJUSTED FOR INTERACTIONS AND CUMULATIVE IMPACTS

We continue to use the simple four stage life history model to illustrate the concepts. The approach is again very simple and draws on conventional population dynamics. When populations traveling across different life history trajectories coincide, there is opportunity for interaction. We model this interaction in the usual way, assuming that survival is related to the density of the competing populations as modeled by the Beverton-Holt survival function.

In order to describe performance profiles for interacting trajectories, we must make some assumptions about the numbers of individuals that each trajectory contributes to each shared life history segment. A simple and consistent reference point for population abundance is the steady state equilibrium condition -- the stable, theoretical abundance and distribution picture that would arise if the environment were to remain constant for a sufficiently long time. The equilibrium abundances are obtained through iterative computer calculations.*

We illustrate the effect of interaction with a hypothetical example. Figure 7 shows the cumulative productivities and capacities for four life history trajectories. The squares indicate performance if the trajectories were independent of one another, the dots show the same trajectories when competition is incorporated. In this example one of the four trajectories is lost (cumulative productivity falls below one) and the others are altered. The purpose of this illustration is not to highlight the modeling results but to demonstrate a method for computing and displaying performance.

To illustrate further how this approach might help stimulate and focus discussion, Figure 8 shows both present and historic performance of trajectories from Figure 7

CONCLUSION

A premise for this paper is that the conceptual framework and performance measures used in watershed management generally, and salmon management specifically, are inadequate. The bottleneck metaphor is cited all too frequently as a basis for discussion (Hall and Field-Dodgson 1981; Reeves et al. 1989; Nickelson, et al. 1993). The bottleneck analogy is useful to understanding capacity, but capacity alone cannot explain observed responses of salmon populations to environmental change. An argument can be made that where protection and enhancement of weak stocks is the priority, productivity is a more critical parameter. But a

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[2] When the iterative calculation is initiated with the equilibrium population for the independent trajectories, it converges relatively quickly. Equilibrium for an independent trajectory is given by:

$$\frac{(\text{CumulativeProductivity} - 1)(\text{CumulativeCapacity})}{(\text{CumulativeProductivity})}$$ for the Beverton-Holt function.

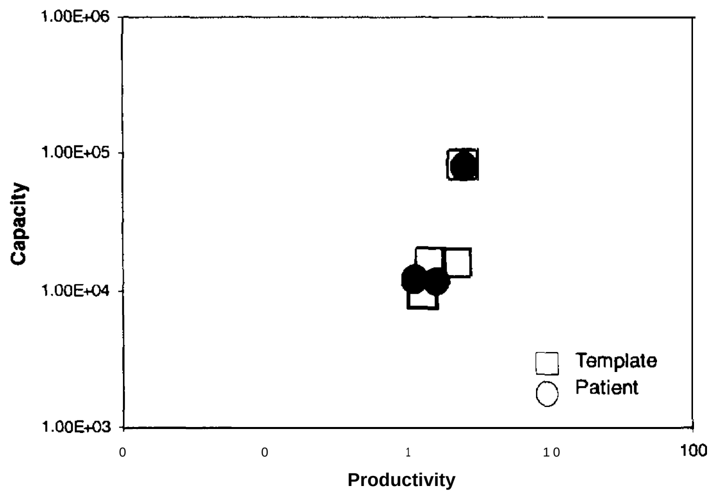

Figure 7. Effect of interaction on performance. This graph depicts a population with access to four trajectories (red, blue, green and black). All of these trajectories have cumulative productivities greater than one, and would persist if no interaction among their occupants occurred. The performance of the independent trajectories are represented by the square shaped symbols. If the trajectories coincide for one or more life stages the performance of all are affected. The filled circles in the graph represent the performance when competition occurs in the juvenile migration stage. Note that the smaller and less productive trajectories are affected the most; one of them is no longer sustained. (Note the scale change from Figure 6.)

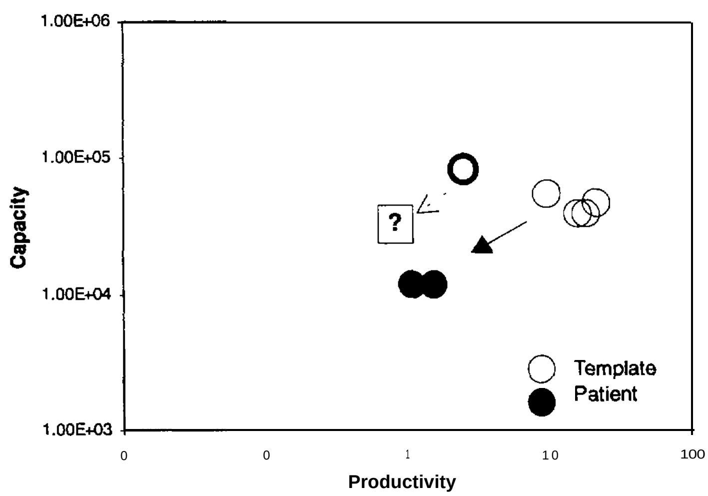

Figure 8. Patient vs Template comparison. Open circles show the Template performance picture. This graph suggests that all that remains of several productive trajectories are a few marginal ones with productivities close to one. The arrow shows the declining trend in population performance due to environmental changes. The grey filled circle is a trajectory that passes through a hatchery; its persistence is a question mark. Competition among occupants of trajectories during shared life history segments are included. This represents an integrated - cumulative analysis of a population aggregate.

framework built only around productivity and capacity is also not sufficient. lt neglects the need for connectivity of habitats that salmon must pass through to complete their life histories. Adding life history diversity as the third component of performance provides the time and space structure needed to deal with connectivity while also allowing for integration of populations where they mingle.

The intent of this paper is to show that discussion of watershed health and salmon performance can incorporate a much greater degree of complexity without loss of clarity. We indeed should include more temporal-spatial detail, more life history complexity, and more watershed specific information.

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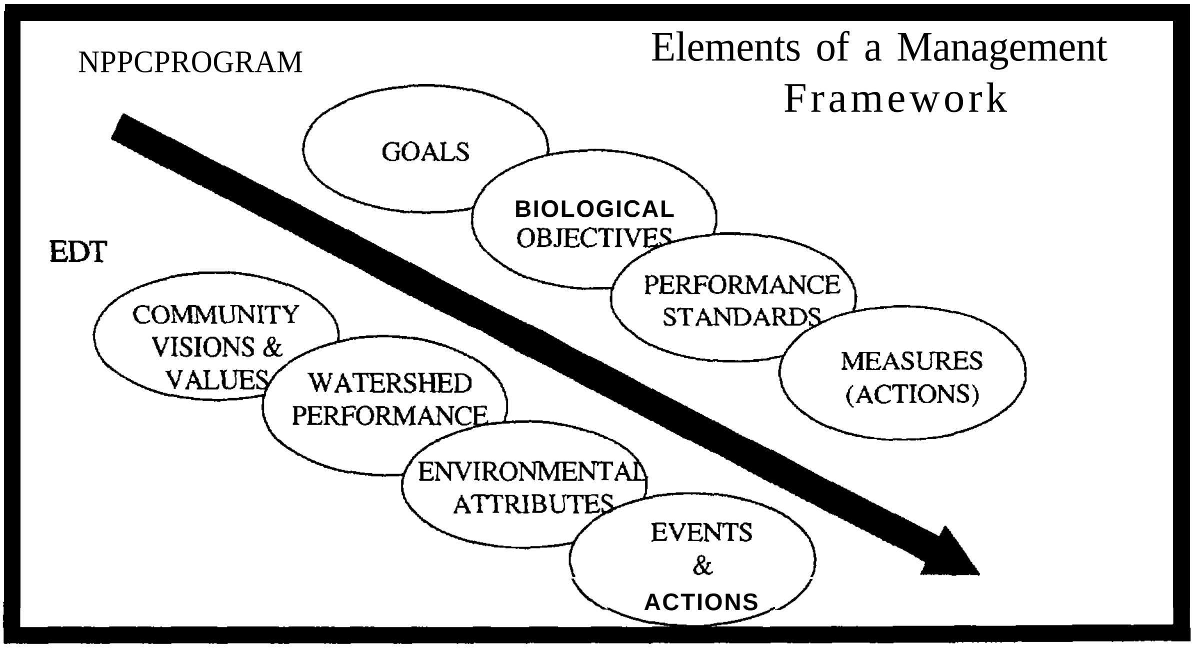

A Strategy for Implementing the Fish and Wildlife Program in an Ecosystem Context

Recommended Approach to Implementation and Monitoring of the Northwest Power Planning Council's Fish and Wildlife Program Consistent with the Ecosystem Diagnosis and Treatment Framework

Two Variations of the Approach are Outlined

May 1996

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A STRATEGY FOR IMPLEMENTING THE FISH AND WILDLIFE PROGRAM IN AN ECOSYSTEM CONTEXT

THE CHALLENGES OF IMPLEMENTATION

The Council's Fish and Wildlife Program (FWP) presents a challenge to those charged with its implementation for at least three reasons:

1. Potential for internal inconsistencies

The program's development process can produce internal inconsistencies both among its measures and between the measures and the stated goals of the program. The FWP identifies one possible inconsistency on page 4-4 in the discussion of the salmon and steelhead goal. There are two parts to the goal: to double the salmon and steelhead runs and to do so without a loss of biological diversity. The program also states "unfortunately, these two resource values -- increased numbers and biological diversity -- often appear to be incompatible." This statement identifies a potential inconsistency and it has important ramifications to the implementation of the program. How should the measures be implemented to minimize conflict between preservation of biodiversity and an increase in numbers? One way to minimize inconsistency is to analyze each measure to determine if a conflict exists with any other measure. A better way to minimize inconsistencies is to develop an overall implementation strategy that includes an analysis of inconsistencies among measures. The overall strategy would not only identify potential conflict between biodiversity and numbers but also other inconsistencies that may be present but not explicitly stated in the program. A strategy for doing that is not part of the program.

2. Consistency with an ecosystem approach

The intent of the FWP is to restore salmon within the context of an ecosystem approach. Achieving that goal not only requires careful selection of the specific measures to be implemented, but there is a need to achieve a balance among the measures implemented. For example, to maintain an ecosystem approach, implementation should be balanced between site specific measures and measures that address entire watersheds.

An ecosystem approach also suggests that salmon should be viewed as a diagnostic in a larger environmental puzzle. An implementation strategy that places salmon restoration in an ecosystem context is called for but not included in the program.

3. Program vs implementation strategy

Another challenge to the implementation of the FWP is its size and complexity and its lack of elements traditionally found in plans such as objectives, tasks, various levels of subtasks, milestones, task dependencies, i.e., a built-in implementation strategy. The latter can be captured on a GANTT or a PERT chart which shows the appropriate implementation sequence among related measures. PERT charts are an important step in critical path analysis which is a tool project managers in both private and public sectors have used for decades in planning and implementing complex engineering and community development projects. Computer tools are available today that make these analyses both easy to conduct and effective to communicate. An implementation strategy is important in any program, but in a program the size and complexity of the FWP it is absolutely necessary. To make the implementation strategy effective it should include some form of critical path analysis.

An implementation strategy for the FWP is equivalent to a road map showing how the region gets from the starting point to salmon restoration using measures contained in the program. The program does not include the road map. The measures are listed in an organized manner that permits orderly and logical presentation, but that gives little insight to the logistics of implementation. The FWP lacks a strategy that takes into account the possible inconsistencies, the need for an ecosystem context, tradeoffs among measures, and the program's complexities. To achieve the plan's potential, an implementation strategy should be developed.

The FWP is an explicit call for change, without an implementation strategy that specifies the sequence of steps and milestones along the path towards such change, it cannot occur.

These observations do not fault the program. They merely point out an additional step that needs to be taken to ensure that the potential of the program is realized. Although the program was developed to fill the need for a cohesive plan, it has not been implemented that way. This was illustrated in the recovery plan prepared by CRITFC. That plan states: had the FWP been implemented in 1982, salmon recovery would now be under way. CRITFC cannot be saying that the program was literally not implemented in the past 15 years, that is obviously not true. CRITFC apparently disagrees with the implementation strategy that has been followed to date. Since there isn't a formal strategy approved by the Council, there is no way to resolve differing opinions on the proper implementation schedule or even for discussing funding priorities. The more complex an undertaking and the greater the number of cooperators the more important the implementation strategy becomes. The FWP certainly is complex and its collaborators many and loosely connected (often even adversaries).

While developing an implementation strategy may require some judgment regarding the Council's intent, it is largely a technical task, that could be completed (using project management tools such as e.g. MS Project) within a relatively short time frame. This analysis might be conducted in stages, and subject to review and confirmation by the Council that its intent is preserved. Some preliminary examples are presented in this report.

STEPS TOWARD AN IMPLEMENTATION STRATEGY

The first step in building an implementation strategy is to develop a set of questions, which when answered, will aid managers and others in their obligations to carry out the FWP on a schedule that is consistent with the intent of the Council. The questions posed below are preliminary and are presented here as examples. Additional work is required to develop a detailed and useful implementation strategy. The final list of questions need to be developed following discussions with appropriate planners and implementers.

Question 1: Is the list of priority projects prepared by the agencies and tribes consistent with the intent of the Fish and Wildlife Program?

The Fish and Wildlife Program gives broad direction in at least two places: in the overall goal to achieve a healthy ecosystem and in the salmon and steelhead goal which contains two directives: double the rune and the preserve biodiversity. Those statements of intent imply that program implementation should be balanced among measures that will further the conservation of biodiversity and those that will increase the number of adult salmon. The overall goal of a healthy ecosystem implies another balancing problem between site specific measures and measures that address problems at the watershed level. An implementation strategy would provide a basis for evaluating funding priorities and tradeoffs while maintaining the intent of the program.

Question 2: Are the projects being implemented in the proper sequence?

Separate measures on a specific topic might include policy development, analysis and review, planning and implementation. Funding for implementation measures should in most cases, follow the completion of policy or planning measures. An implementation strategy will identify sequences of measures and thus make it possible to evaluate whether implementation is proceeding in the appropriate order.

Question 3: Is the program being implemented in a way that is consistent with the interaction among measures?

There is interaction among measures and in some cases that interaction must be considered in the implementation sequence. For example, supplementation measures are linked to measures dealing with carrying capacity, watershed planning, and habitat restoration. In some cases, supplementation must follow completion of habitat restoration. Supplementation projects that do not recognize linkages with other measures or are being implemented out of the appropriate sequence should be given critical evaluation and review. An implementation strategy will identify the linkages among measures in different sections of the Fish and Wildlife Program.

Question 4: Have the assumptions associated with specific measures been identified and documented?

Most measures have uncertainties associated with them which means there is a degree of risk associated with their implementation. For each uncertainty there is an implied or stated assumption. For example, most supplementation projects contain the implied assumption that habitat in the stream to be stocked and habitat in the migratory route to the sea are capable of supporting additional natural production. The assumptions associated with a measure must be identified and incorporated into the design and implementation of a project. A list of overall assumptions associated with groups of related measures will aid in evaluating the design of implementation projects.

To answer those questions and any others that are identified the measures contained in the FWP will be converted into a data base which can be manipulated and queried to provide appropriate summaries of information about the program. We constructed a preliminary data set based on measures contained in Section 7 of the FWP and queried it to construct examples of the kind of basic information that could be used to develop an implementation strategy. The results of those queries are shown in Tables 1 - 6.

A cursory review of the tables shows some interesting patterns. In section 7, the Council placed a great deal of emphasis on planning and policy development (Tables 1 and 6). A total of 114 measures contain planning or policy development. An emphasis on planning suggests that there is a lot of uncertainty associated with the measures in Section 7. Significant uncertainty means that monitoring and evaluation measures should be a priority. In addition, it seems critical that many of the policy measures should be completed before funding implementation measures in the same topic area. It also suggests that identification and documentation of critical assumptions (i.e. those subject to uncertainty) prior to implementation is important (Question 4). Even though the FWP stresses the need to conserve biodiversity there are only 2 measures in section 7 that directly address that subject (Table 4). Since there are only two measures they should have a high priority. The same argument could be made for watershed measures (Table 3). Measures that address entire watersheds are important to achieve the Council's goal of ecosystem health. Since there are only 10 watershed measures, a high percentage of them should be funded. Tables 1 - 6 illustrate the types of information that will be extracted from the data base and used to develop an implementation strategy.

An important part of the implementation strategy will be the display of clusters of related measures in a PERT format. The PERT charts of related measures shows the implementation sequence, the relationships among measures and constraints. We have developed a preliminary example of a PERT description of the supplementation measures contained in Section 7 (Figure 1). This example is not complete; it is presented here to give a preliminary view of an important part of the implementation strategy.

The main sequence of supplementation measures are: 7.3B. 1 develop the plans, 7.3B.3 obtain NMFS approval, and 7.3B.2 implement the plans. Two additional measures are not in the main sequence of measures but must be implemented parallel to it. Those are 7.3A. 1 develop RASP further and 7.3B.4 develop NMFS policy. There are several measures that are indirectly related to supplementation. It's important that the related measures be implemented in a timely manner so they can provide input to the main sequence. In some cases (7.2B.1,7.2A and 7.1F) the related measures provide critical information and must be implemented before or concurrent with the supplementation sequence. The PERT chart indicates that some measures that are only indirectly related to supplementation will provide information critical to its success. This reinforces the need to implement measures in a sequence that ensures that the exchange of critical information is possible.

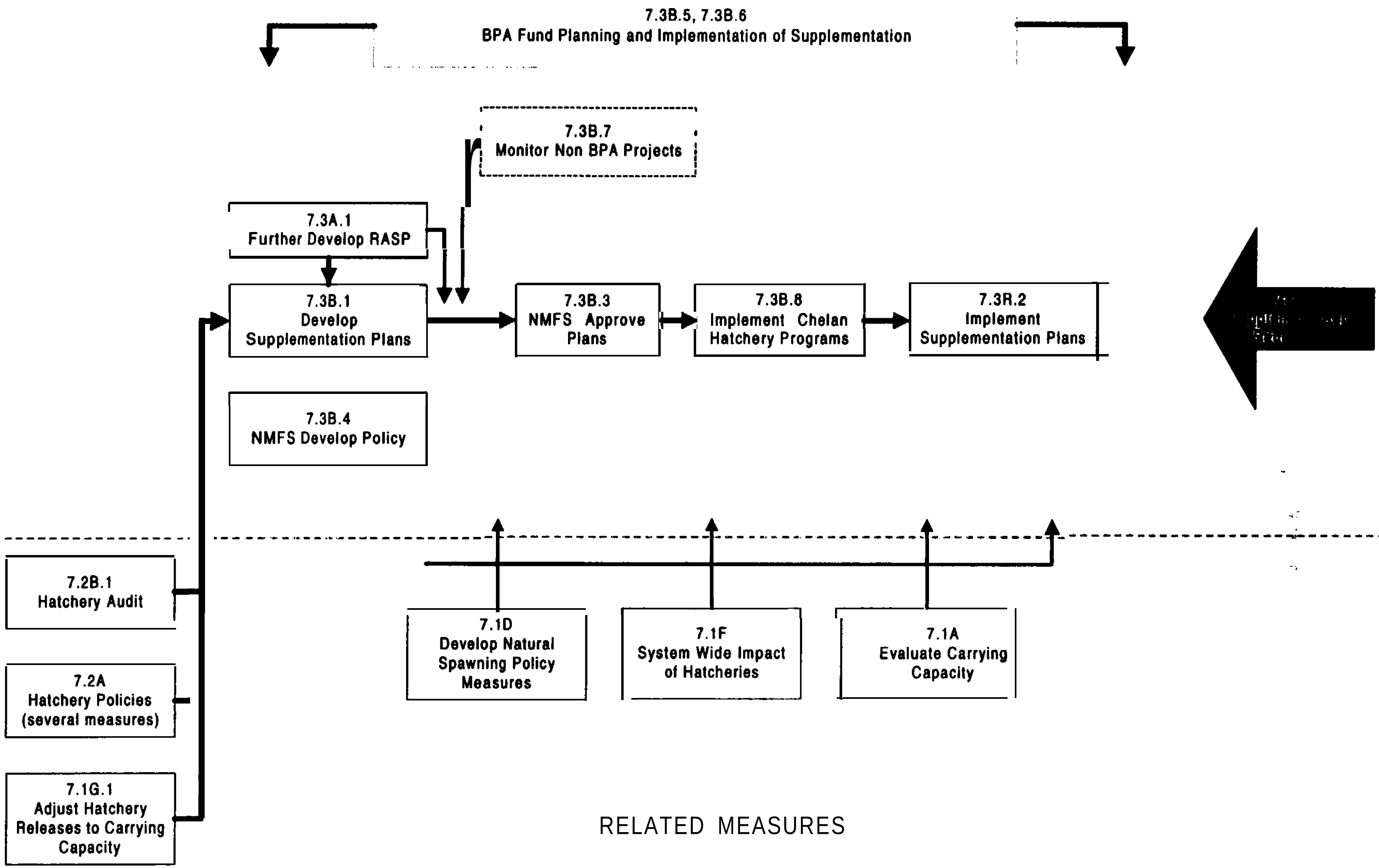

Figure 1. **PERT chart for supplementation measures in the FWP. For illustrative purposes only.**

Table 1. Planning Measure identified in Section 7 of the FWP.

Measure Identifier	Measure
7.0A Identify and implement emergency production and habitat actions in 1995 and 1996	
	7.0A.1
7.0B Ten-year implementation plan for production and habitat projects	
	7.0B.1
7.0C Regular Updating and Distribution of Subbasin Plans	
	7.0C.1
	7.Oc.4
7.1A Evaluation of carrying capacity	
	7.1A.2
	7.1A.5
7.1B Conserve Genetics Team	
	7.1B.1
	7.1B.2
7.1 C Collection of population status, life history & other data on wild & naturally spawning populations	
	7.1C
	7.1C.2
	7.1c.3
	7.1C.4
7.1 D Wild and naturally spawning population policy	
	17.1D.2
7.1 F Systemwide & cumulative impacts of existing & proposed artificial production projects.	
	7.1F.1
	17.1F.3
7.1G Adjust total number of hatchery fish released to stay within basin carrying capacity	
	7.1G.1
Biodiversity	
	7.1I.1
7.2A Hatchery policies, coordination and operations	
	7.2A.1
	7.2A.3
	7.2A.4
	7.2A.5
	7.2A.10
7.2D Improved propagation at existing facilities	
	17.2D.7
7.3A Regional assessment of supplementation	
	7.3A.1

Table 1 cont'd.Planning Measure identified in Section 7 of the FWP.

Measure Identifier	Measure
7.3B Final planning and implementation of proposed additional high priority supplementation projects	
	7.3B.1
	7.3B.5
	7.3B.8
7.4A Identify, evaluate and implement new production initiatives	
	7.4A.1
	7.4A.2
7.4B Develop master plans	
	7.4B.1
7.4D Captive brood stocks	
	7.4D.1
7.4E Cryopreservation	
	7.4E.1
7.4F Portable facilities for adult salmon collection and holding, and for juvenile salmon acclimation	
	7.4F.1
7.4G Ringold Hatchery site enhancement and water development	
	7.4G.1
	7.4G.2
7.4H Reintroduction of anadromous fish in the upper Cowlitz River Basin	
	7.4H.1
7.4J John Day acclimation facilities	
	7.4J.1
	7.4J.2
	7.4J.4
7.4K Yakima production facilities	
	(7.4K.1
7.4L Northeast Oregon production facilities	
	7.4L.1
7.4M Nez Perce tribal hatchery	
	17.4M.2
7.40 Small-scale production projects	
	7.4O.1
7.5A Snake River sockeye salmon	
	7.5A.1
	7.5A.2
	7.5A.3
7.5B Snake River fall chinook salmon	
	7.5B.1
	7.5B.4

Table 1 cont'd.Planning Measure identified in Section 7 of the FWP.

Measure Identifier	Measure
7.X Lower Columbia River coho salmon	
	7.5C.1
	7.5C.3
7.5D Columbia River chum salmon	
	7.5D.1
	7.5D.2
7.5E Columbia River sea-run cutthroat trout	
	7.5E.1
	7.5E.2
	7.5E.5
7.5F Pacific lamprey	
	7.5F.1
7.6B Habitat policies	
	7.6B.2
7.7A Coordination of watershed activities	
	7.7A.1
	7.7A.4
	7.7A.5
7.7B Model Watersheds	
	7.7B.2
7.8A Land management	
	7.8A.2
	7.8A.3
	7.8A.5
	7.8A.8
7.8B Best management practices	
	7.8B.1
7.8E Land exchanges, purchases and conservation easements	
	7.8E.1
7.8F Water regulation	
	7.8F.4
7.8H Water conservation	
	7.8H.2
	7.8H.4
7.9A Willamette Subbasin	
	7.9A.1
	7.9A.2
	7.9A.3
	7.9A.5

Table 1 cont'd.Planning Measure identified in Section 7 of the FWP.

Measure Identifier	Measure
7.9B Umatilla Subbasin	
	7.9B.3
	7.9B.12
7.1OA Update priorities and continue to fund and implement an accelerated screening and passage	
	7.10A.1
	17.10A.4
7.10H Leaburg and Walterville Facilities	
	7.10H.1
	7.10H.3
	7.10H.4
7.101 Foster Dams	
	7.10I.1
7.10J Marmot Dam	
	7.10J.1
7. I OK Passage into historic habitat	
	7.10K.1
7.11 A Additional water storage	
	7.11A.1
	7.11A.4

Table 2. Natural production measures in Section 7 of the FWP.

Measure Identifier	Measure	Nat Production	Spawning	Rearing	Smolt to Adult Rearing	Adult Migration
7.0A Identify and implement emergency production and habitat actions in 1995 and 1996						
	7.0A.1		X	X		
	7.0A.2		X	X		
	7.0A.3		X	X		
	7.0B.1	X				
	7.0B.2	X				
	7.0B.3	X				
	17.0B.4	X				
7.0C Regular Updating and Distribution of Subbasin Plans						
	17.0C.4	x				
7.1A Evaluation of carrying capacity						
	7.1A.1	X				
	7.1A.3				X	
7.1C Collection of population status, life history & other data on wild & naturally spawning populations						
	7.1C.3	X	X	X	X	X
	7.1C.4	X	X	X	X	X
7.1D Wild and naturally spawning population policy						
	7.1D.1	X	X	X	X	X
	7.1D.2	X	X	X	X	X
7.1F Systemwide & cumulative impacts of existing & proposed artificial production projects.						
	7.1F.1	X	X	X	X	X
7.1G Adjust total number of hatchery fish released to stay within basin carrying capacity						
	7.1G.1			X	X	
7.2D Improved propagation at existing facilities						
	7.2D.6	X				
7.4H Reintroduction of anadromous fish in the upper Cowlitz River Basin						
	7.4H.1	X				
7.4J John Day acclimation facilities						
	7.4J.1	X				
7.5B Snake River fall chinook salmon						
	7.5B.3	X				
7.5C Lower Columbia River coho salmon						
	7.5C.1	X				
	7.5C.3	X				
	7.5C.4	X				
	7.5C.5	X				
	7.5C.6	X				

Table 2 cont'd.Natural production measures in Section 7 of the FWP.

Measure Identifier	Measure	Nat Production	Spawning	Rearing	Smolt to Adult Rearing	Adult Migration
7.5D Columbia River chum salmon						
	7.5D.1	X				
	7.5D.3	X				
	7.5D.4	X				
	7.5D.5	X				
7.5E Columbia River sea-run cutthroa		X				
	7.5E.1	X				
	7.5E.3	X				
	7.5E.4	X				
7.5F Pacific lamprey						
	7.5F.1	X				
7.6A Habitat Goal						
	7.6A.1	X				
	7.6A.2	X				
7.6B Habitat policies						
	7.6B.1	X				
7.7A Coordination of watershed activities						
	7.7A.1	X				
7.7B Model Watersheds						
	7.7B.2	X				
7.8J Water aailability						
	7.8J.2		X			X
7.9A Willamette Subbasin						
	7.9A.4		X	X		
	7.9A.8		X	X		
7.9B Umatilla Subbasin						
	7.9B.7	X				
	7.9B.10	X				
	7.9B.11	X				
7.10A Update priorities and continue to fund and implement an accelerated screening and passage						
	7.10A.1			X		
	7.10A.2			X		
	7.10A.3			X		
	7.10A.4			X		
	7.10A.5			X		
	7.10B.1	X				
7.10C Enloe Dam						
	7.10C.1	X				
7.10E Green Peter Dam						
	7.10E.1	X	X	X		X

Table 2 cont'd.Natural production measures in Section 7 of the FWP.

Measure Identifier	Measure	Nat Production	Spawning	Rearing	Smolt to Adult Rearing	Adult Migration
7.10F Willamette Falls						
	7.10F.1					X
7.10G Clackamas River Dams						
	7.10G.1					X
7.10H Leaburg and Walterville Facilities						
	7.10H.1					X
	7.10H.3					X
7.10K Passage into historic habitat						
	7.10K.1	X				
7.11B Passage						
	7.11B.1					X
	7.11B.2	X				X
	7.11B.3					X
7.11C Flows						
	7.11C.1		X	X		X
	7.11C.2		X	X		X
7.11C	7.11C.3		X	X		X

Table 3. Watershed measures in Section 7 of the FWP.

Measure Identifier	Measure
7.7A Coordination of watershed activities	
	7.7A.1
	7.7A.2
	7.7A.3
	7.7A.4
	7.7A.6
7.7B Model Watersheds	
	7.7B.1
	7.7B.2
	7.7B.3
	7.7B.4
7.8H Water Conservation	
	7.8H.2

Table 4. Biodiversity measures in Section 7 of the FWP.

Measure Identifier	Measure
7.1D Wild and naturally spawning population policy	
	7.1D.2
7.11 Biodiversity institute	
	7.1I.1

Table 5. **Artificial propagation measures in Section 7 of the FWP.**

Measure Identifier	Measure	Artificial Propagation	Captive Brood	Conventional Hatchery	Supplemen-tation
7.0A Identify and implement emergency production and habitat actions in 1995 and 1996					
	7.0A.1				X
	7.0A.2				X
	7.0A.3				X
7.0B Ten-year implementation plan for production and habitat projects					
	7.0B.1	X			
	7.0B.2	X			
	7.0B.3	X			
	7.0B.4	X			
7.0C Regular updating and distribution of subbasin plans					
	7.0C.4	X			
7.0D Comprehensive environmental analysis of federal production activities					
	7.0D			X	
7.1A Evaluation of carrying capacity					
	7.1A.1	X			
7.1B Conserve genetics team					
	7.1B.2	X			
7.1D Wild and naturally spawning population policy					
	7.1D.1	X			
	7.1D.2	X			
7.1F Systemwide & cumulative impacts of existing & proposed artificial production projects.					
	7.1F.1	X			
	7.1F.2	X			
	7.1F.3	X			
7.1G Adjust total number of hatchery fish released to stay within basin carrying capacity					
	7.1G.1	X			
	7.1H.1	X			
	7.1H.2	X			
	7.1H.3	X			
7.2A Hatchery policies, coordination and operations					
	7.2A.1	X			
	7.2.A.2	X			
	7.2A.3	X			
	7.2A.4	X			
	7.2A.5	X			
	7.2A.6	X			
	7.2A.7	X			
	7.2A.8	X			
	7.2A.9	X			

Table 5 cont'd. Artificial propagation measures in Section 7 of the FWP.

Measure Identifier	Measure	Artificial Propagation	Captive Brood	Conventional Hatchery	Supplementation
	7.2A.10	X			
	7.2A.11	X			
7.2B Hatchery evaluation					
	7.2B.1	X			
	7.2B.2	X			
7.2C Creative partnerships in hatchery production					
	7.2C.1	X			
	7.2C.2				
7.2D Improved propagation at existing facilities					
	7.2D.1	X			
	7.2D.2	X			
	7.2D.3	X			
	7.2D.4	X			
	7.2D.5	X			
	7.2D.6	X			
	7.2D.7	X			
7.3A Regional assessment of supplementation					
	7.3A.1				X
7.3B Final planning and implementation of proposed additional high priority supplementation projects					
	7.3B.1				X
	7.3B.2				X
	7.3B.3				X
	7.3B.4				X
	7.3B.5				X
	7.3B.6				X
	7.3B.7				X
	7.3B.8	X			
7.4A Identify, evaluate and implement new production initiatives					
	7.4A.1	X			
	7.4A.2	X			
7.4B Develop master plans					
	7.4B.1	X			
7.4C Emergency cases					
	7.4C.1	X			
	7.4C.2	X			
7.4D Captive brood stocks					
	7.4D.1	X			
	7.4D.2	X			

Table 5 **cont'd. Artificial** propagation measures in Section 7 of the FWP.

Measure Identifier	Measure	Artificial Propagation	Captive Brood	Conventional Hatchery	Supplemen-tation
7.4E Cryopreservation					
	7.4E.1	X			
	7.4E.2	X			
7.4F Portable facilities for adult salmon collection and holding, and for juvenile salmon acclimation					
	7.4F.1	X			
	7.4F.2	X			
7.4G Ringold Hatchery site enhancement and water development					
	7.4G.1	X			
	7.4G.2	X			
7.4I Umatilla production facilities					
	7.4I.1	X			
	7.4I.2	X			
7.4J John Day acclimation facilities					
	7.4J.1	X			
	7.4J.2	X			
	7.4J.3	X			
	7.4J.4	X			
	7.4J.5	X			
7.4K Yakima production facilities					
	7.4K.1				X
7.4L Northeast Oregon production facilities					
	7.4L.1	X			X
	7.4L.2	X			
7.4M Nez Perce tribal hatchery					
	7.4M.1	X			X
	7.4M.2	X			
	7.4M.3	X			
7.4N Pelton Dam fish ladder					
	7.4N.1	X			
	7.4N.2	X			
7.4O Small-scale production projects					
	7.4O.1	X			
7.5A Snake River sockeye salmon					
	7.5A.1	X	X		
	7.5A.2	X	X		
	7.5A.3				X
7.5B Snake River fall chinook salmon					
	7.5B.1		X		X
	7.5B.2		X		X

Table 5 cont'd. Artificial propagation measures in Section 7 of the FWP.

Measure Identifier	Measure	Artificial Propagation	Captive Brood	Conventional Hatchery	Supplementation
	7.5B.4		X		X
7.5D Columbia River chum salmon					
	7.5D.2				X
7.5E Columbia River sea-run cutthroat trout					
	7.5E.2				X
7.7A Coordination of watershed activities					
	7.7A.1	X			
7.7B Model Watersheds					
	7.7B.2	X			
7.9B Umatilla Subbasin					
	7.9B.7	X			
	7.9B.10	X			
	7.9B.11	X			

Table 6. Policy measures contained in Section 7 of the FWP.

Measure Identifier	Measure
7.1D Wild and naturally spawning population policy	
	7.1D.1
7.2A Hatchery policies, coordination and operations	
	7.2A.6
7.4C Emergency cases	
	7.4C.2
7.4H Reintroduction of anadromous fish in the upper Cowlitz River Basin	
	7.4H.1
7.5B Snake River fall chinook salmon	
	17.5B.4
7.5C Lower Columbia River coho salmon	
	7.5C.1
	7.5c.5
	7.5C.6
7.5D Columbia River chum salmon	
	7.5D.1
	7.5D.4
	7.5D.5
7.5E Columbia River sea-run cutthroat trout	
	7.5E.1
	7.5E.4
	7.5E.5
7.6A Habitat goal	
	7.6A.1
	7.6A.2
7.6B Habitat policies	
	7.6B.1
	7.6B.3
	7.6B.4
	7.6B.6
7.8A Land management	
	7.8A.1
7.8B Best management practices	
	7.8B.1
7.8F Water regulation	
	7.8F.1
7.8H Water conservation	
	7 8H.1

Table 6 cont'd. Policy measures contained in Section 7 of the FWP.

Measure Identifier	Measure
7.9A Willamette Subbasin	
7.9A	17.9A.5
7.10A Update priorities and continue to fund and implement an accelerated screening and passage	
	7.10A.5
	7.10A.7
7.11 A Additional water storage	
	7.11A.3
	17.1 IA.4

ORGANIZATION OF THE FISH AND WILDLIFE PROGRAM CONSISTENT WITH AN ECOSYSTEM PERSPECTIVE
(A VARIATION OF THE APPROACH)

PURPOSE

The Columbia River Basin Fish and Wildlife Program is an effort to implement measures to protect and improve the sustainability of fish and wildlife of the basin, while providing for sustained benefits of the basin's resources to society. The Program is supposed to be built around an ecosystem concept by treating the basin as an interconnected ecosystem. Therefore, a system-wide approach has been called for, one that is to provide for a balance of measures across the ecosystem.

Balance in this case does not simply mean dispersing measures evenly throughout the basin. To be effective, the measures need to complement and build upon one another, consistent with ecosystem organization and function.

Such an approach has a logical requirement--it should be possible to organize and view the Program in a way that is consistent with ecosystem organization and function. Seeing, or understanding the Program in this manner would provide what we refer to as an ecosystem perspective. This perspective would better enable managers to balance and prioritize the large and diverse number of measures that have been outlined in the Program.

The purpose of this task is to provide a way of organizing, and subsequentially viewing, the components of the Program consistent with an ecosystem perspective.

WHAT CONSTITUTES AN ECOSYSTEM PERSPECTIVE?

Ecological processes function in geographic space and time. An ecosystem perspective is gained by considering how basic ecological processes are affected by Program measures in spatial and temporal scales relevant to Program objectives and high priority species groups. In a sense, the Program treats these species groups as indicators of overall basin condition for sustainability.

This perspective, therefore, must consider the effect of measures through two questions:

1. How do Program measures apply in space and time scales relevant to key species groups?

2. What ecosystem functions (or environmental conditions) in space and time are the intended targets of Program measures?

The Program considers salmonid species as **high priority** species.

Spatial scales relevant to salmonids, particularly anadromous salmonids, need to be organized hierarchically, allowing for a scale smaller than the subbasin, extending to subbasin, ecoregion, then entire basin.

The temporal scale needs to be consistent with individual life stages of salmonids, because ecological conditions affect life stages differently, and ecological conditions vary seasonally.

Ecosystem functions can be characterized by three aspects of biological performance: biodiversity (either as species or life history diversity), productivity (or sustainability), and capacity (or overall abundance--including potential abundance).

APPROACH

The approach to organizing, then viewing, Program components would consist of scoring all measures according to criteria that characterize the spatial and temporal scales described above and the relevant aspects of biological performance.

In addition, all measures would be scored by several attributes within each of three categories: ecosystem **performance, management** activity, and **type** of programmatic role.

Each measure would be scored in each attribute within each category (as defined below) on a scale of -1 to 3 to describe the extent of relationship between the measure and the category. The purpose of this type of scoring is to describe the level of specificity of the measure. Some measures are very specific and clearly are intended to have an effect on a certain ecological attribute, while others are much less clear.

Numeric codes for scoring are listed below:

-1	0	1	2	3
Measure contradicts attribute	Measure has no relationship to attribute	Measure possibly has relationship to attribute	Measure has likely relationship to attribute	Measure has definitive relationship to attribute

DESCRIPTION OF DATABASE AND RELEVANT CATEGORIES

All classification and scoring of Program measures would be entered into a database to permit ease of organizing and summarizing information. Microsoft Access 2.0 software would be used. The information would also be listed in Microsoft Excel spreadsheet software to aid review and use by individuals more comfortable with this format.

Each record within the database would define a measure and the scores that are given to it. Categories (or attributes) that define each record are listed below, shown grouped according to major category:

Program code (this identifies the specific program being considered)
Measure code (identifies specific measure considered)
Measure title
Measure description

Applicable location(s) (identifies applicable spatial location and scale)
Applicable species (all or specific)
Applicable life stage(s) (all or specific)
Applicable time period(s) (all or seasonal)

Performance - Broad based (not specific to subcategories)
Performance - Biodiversity - Broad based biodiversity (not specific to subcategories)
Performance - Biodiversity - Species diversity
Performance - Biodiversity - Life history diversity
Performance - Biodiversity - Stock characteristics (ID, etc.)
Performance - Biodiversity - Ecological interactions
Performance - Productivity/sustainability
Performance - Capacity/abundance/numbers

Management - Broad based management
Management - Habitat (includes improvement measures)
Management - Passage
Management - Harvest
Management - Conventional hatcheries
Management - Supplementation

Type - Broad based measure type
Type - Planning
Type - Coordination
Type - Monitoring or evaluation (can include analysis or review)
Type - Implementation
Type Research

INFORMATION SUMMARY AND DISPLAY

Results of scoring would be summarized and displayed as a series of charts. The various categories would be displayed in space and time scales to permit ease of interpreting how the measures are distributed in these dimensions.